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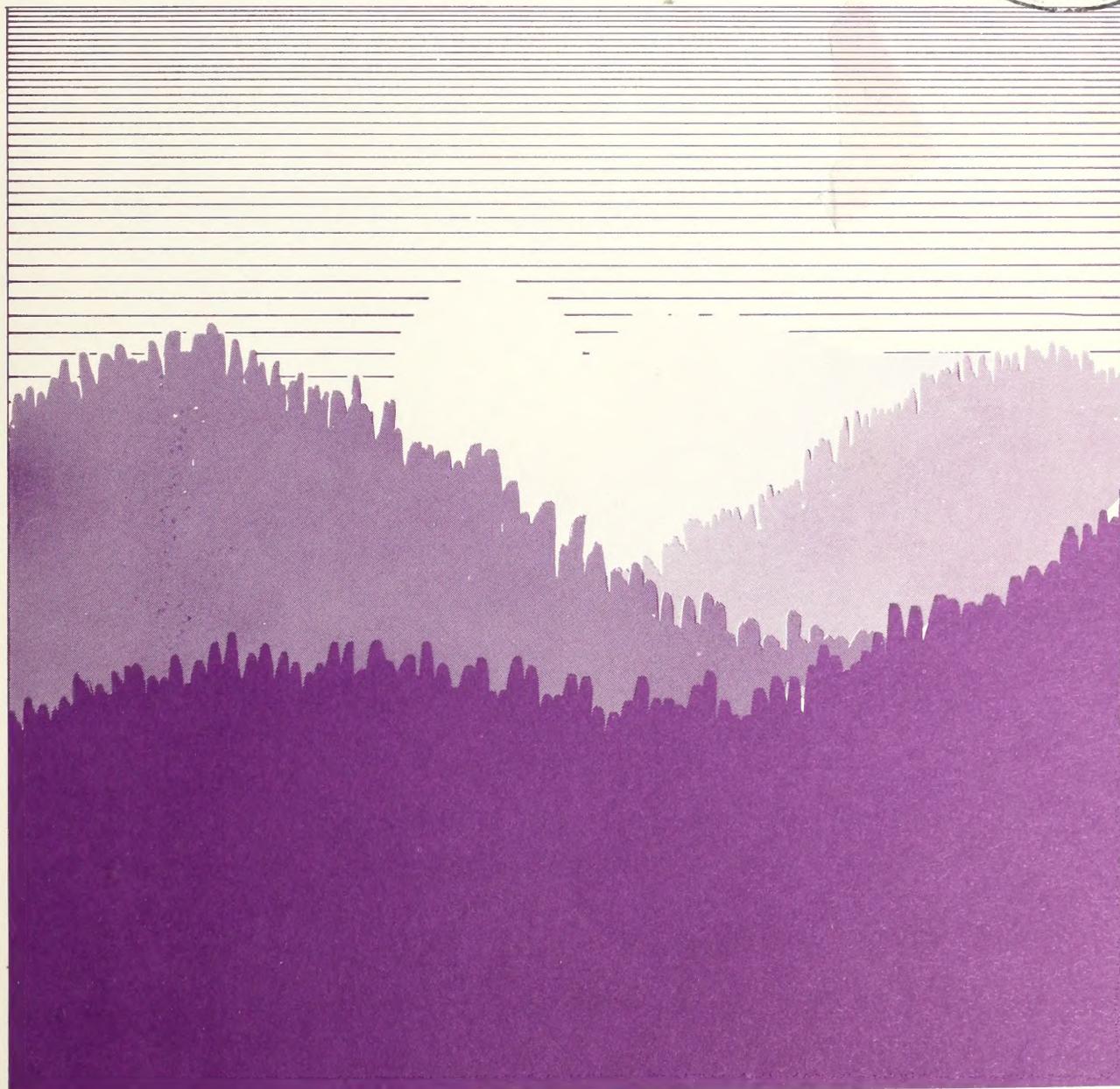
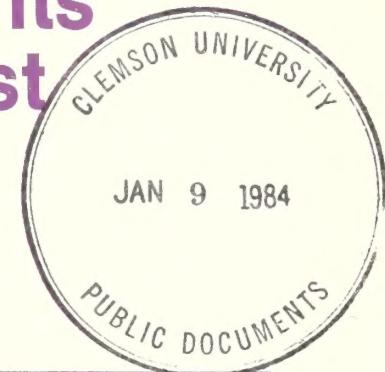
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# Forest Community Classification of the Porcupine River Drainage, Interior Alaska, and Its Application to Forest Management

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## Abstract

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The forest vegetation of 3 600 000 hectares in northeast interior Alaska was classified. A total of 365 plots located in a stratified random design were run through the ordination programs SIMORD and TWINSPLAN. A total of 40 forest communities were described vegetatively and, to a limited extent, environmentally. The area covered by each community was similar, ranging from 0.29 to 4.29 percent. A large number of mixed spruce communities were described and suggested to be the result of the study area's proximity to the northern limit of black spruce (*Picea mariana* (Mill.) B.S.P.). Average aboveground tree biomass and productivity were estimated for each community. Values for trees ranged from 0.2 kilogram per square meter aboveground biomass and 4.0 grams per square meter per year mean annual increment for a woodland black spruce community to 23.4 kilograms per square meter and 195 grams per square meter per year for a closed white spruce community. The potential productivity of the study area was estimated on the basis of 100-percent stocking of each community with trees. A total of 42.9 percent of the area was estimated to have potential to support commercial forests.

**Keywords:** Classification (forest communities), biomass, Alaska (Porcupine River drainage).

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## Introduction

Interior Alaska is developing at an ever increasing pace. In 1977 the Trans-Alaska Oil Pipeline was the first large project to cross the interior taiga, and it indicated a definite need for basic ecological information about taiga ecosystems. Future development might include a natural gas pipeline and extensive land clearing for agricultural development, plus a need to supply the increasing demand for forest products initially in the local market and eventually in the world market.

Wise management of taiga ecosystems will require substantially more basic ecological knowledge than is available for interior Alaska. It will also require that this knowledge be effectively organized and disseminated. Classification of ecosystems into relatively homogenous groups to aid in the description and interpretation of ecological data is probably the most commonly used technique. The complexity of the classification then varies by the size of the study and its objectives. When enough information is available, the classifications are linked. Viereck and Dyrness published a preliminary classification of Alaska vegetation in 1980.

Few studies have been carried out in the Alaska taiga. The basic ecological effects of forest fires on vegetation, soils, hydrology, and wildlife were studied by Lutz (1956). He used a simple vegetation classification by dominant overstory tree to organize and present results. He presented successional patterns after fire and showed the tremendous effect that forest fires have on vegetation in the taiga of Alaska. Drury (1956) used a more detailed classification of the physiographic processes that influence the vegetative structure of the bog flats of the upper Kuskokwim River.

The use of quantitative methods to classify the vegetation of interior Alaska and then to interpret the classification structure in an environmentally meaningful way is also limited to a few studies. Taiga communities in northwest Alaska were described and compared with other arctic regions by Hanson (1953). Foote<sup>1/</sup> (1979) classified and described communities in interior Alaska and suggested a general pattern of forest succession. A vegetation classification was also developed for a portion of northeast Alaska as part of the environmental studies before construction of the Trans-Alaska Oil Pipeline (Hettinger and Janz 1974).

A study of the structure and function of taiga ecosystems in the vicinity of Fairbanks, Alaska, has focused on the effect of cold soil temperatures as a major factor controlling the distribution and structure of taiga ecosystems (Van Cleve and others 1983). The effect of soil temperature on production and nutrient cycling in two black spruce (*Picea mariana* (Mill.) B.S.P.) ecosystems has been presented by Van Cleve and others (1980). These studies represent an attempt to start with a hypothesized control over community structure and function before sampling. Vegetation-environment studies can then be designed to test the hypothesis rather than formulate a hypothesis as is the case in many vegetation classification studies.

<sup>1/</sup> Foote, J. Classification, description and dynamics of plant communities following fire in the taiga of interior Alaska. 1976. 211 p. Final report for the Bureau of Land Management, U.S. Department of the Interior. On file at Institute of Northern Forestry, Fairbanks, Alaska.

During the summer of 1977 and 1978, a multiresource inventory of a 3 600 000-ha area of northeastern interior Alaska resulted in an opportunity for gathering vegetation and environmental data on a large scale. Work in such an extensive area could confirm that the relationships between vegetation structure and function and the environment were similar to patterns observed and hypothesized in detailed studies from a limited area around Fairbanks.

The first paper from the study was a detailed report of the fire cycles in the study area (Yarie 1981). The objective of this phase of the study was to prepare a detailed vegetation classification of the forest communities and to relate the community structure to the potential for forest management.

## Study Area

The 3 600 000-ha study was centered around the Porcupine and Upper Yukon River drainages (fig. 1). The area corresponds to the Porcupine inventory unit of the USDA Forest Service. The area has four physiographic divisions (Wahrhaftig 1965). The two major divisions are the Yukon Flats and the Porcupine Plateau (fig. 1).

The Yukon Flats consists of marshy lake-dotted flats ranging in elevation from 91 to 275 m. The northern part is made up of gently sloping outwash fans of the Sheenjek River or nearly flat flood plains. Rolling silt- and gravel-covered marginal terraces rise above the flats and slope gradually to altitudes of about 460 m. Permafrost underlies most of the section except rivers, recently abandoned meander belts, and large thaw lakes.

The Porcupine Plateau is dominated by low ridges with gentle slopes and rounded to flat summits 460 to 762 m above sea level. Valley floors are broad and valley patterns irregular. The entire section is underlain by continuous permafrost.

The other two divisions occupy only small areas near the Canadian border and are not described.

The climate is continental subarctic. Temperature extremes vary widely; Fort Yukon had a record high of 37.8°C and low of -61°C in 40 years of recordkeeping. Weather data from other locations in the area are minimal; only four locations reported data with a period of record ranging from 4 to 6 years. The climate is relatively uniform over the study area, with a slight decrease in mean annual temperature from the southwestern to the northeastern portion. Annual precipitation is low, averaging less than 25.4 cm a year. The average annual precipitation for Fort Yukon is 15.4 cm. This combination of low precipitation and high summer temperatures results in the most extreme fire climate in Alaska (Trigg 1971).

## Methods

Field sampling was done during the forest inventory of the Porcupine area. A stratified random sampling design was used (Hegg 1974, Hegg and Sieverding 1979). A total of 529 0.4-ha sample plots were visited during the survey period.

## Vegetative Cover

A reconnaissance plot approach (Franklin and others 1970) was used to obtain percent cover for all vascular and nonvascular plants in each 0.4-ha sample plot. Understory plants were identified by genus and species when possible. Identification was made in the field, except for a few samples that were sent to Fairbanks for identification at the USDA Forest Service Institute of Northern Forestry or the University of Alaska Herbarium.

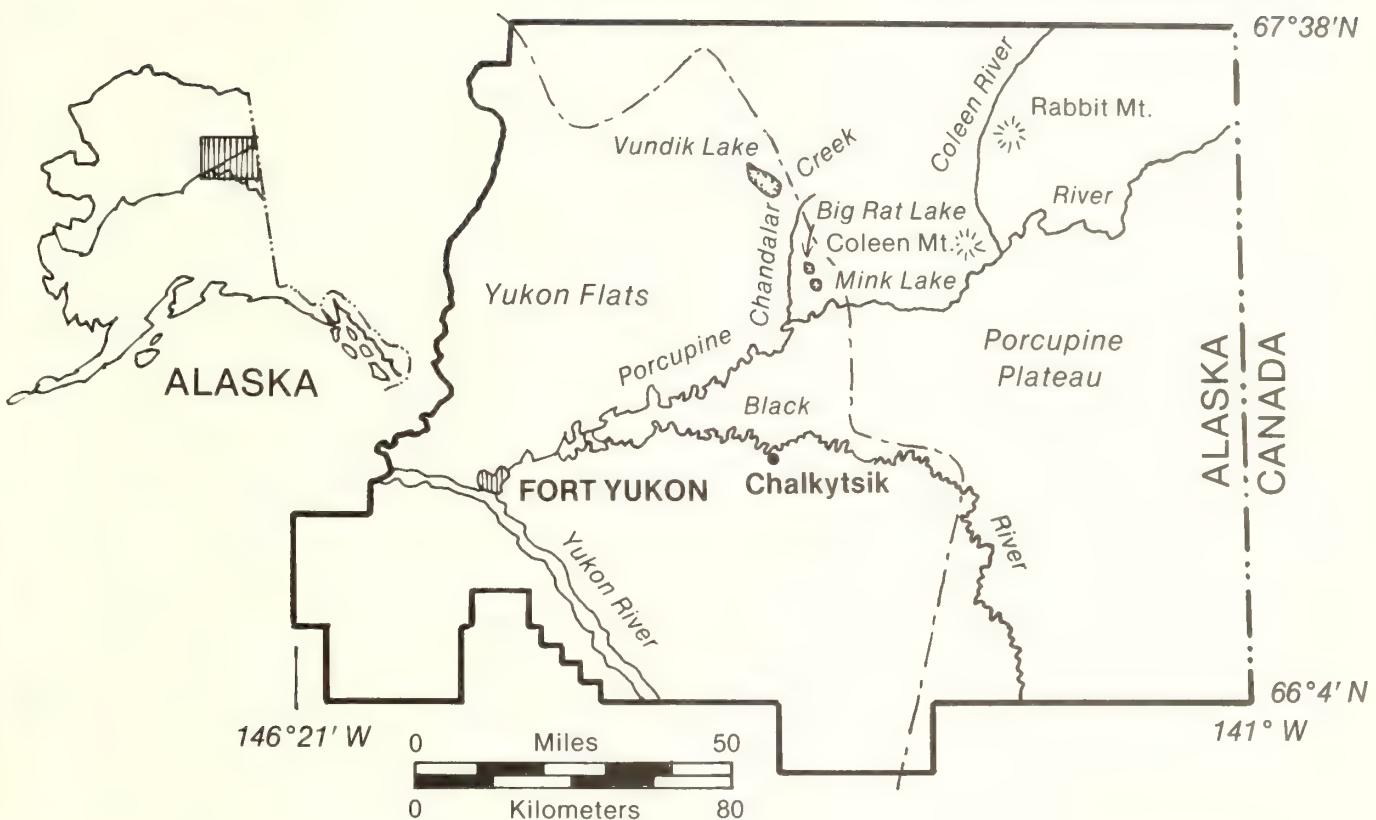


Figure 1.—The Porcupine study area. The dashed line (--) is the approximate delineation between the two major physiographic sections, Yukon Flats and Porcupine Plateau.

Percent cover for overstory trees was estimated from the tree measurements taken by the forest survey crew, using the Domin-Krajina scale (Krajina 1933). Cover values represented the midpoint of a range of values. Cover values for the understory species were adjusted to represent the midpoint of the appropriate range.

Values for species were coded into a vegetative layer based on overstory or understory height:

<u>Layer</u>	<u>Description</u>
A1	Dominant and codominant trees
A2	Intermediate trees
A3	Suppressed trees
B2	Tree seedlings
C	Shrubs between 2 and 10 m in height
DH	Shrubs and woody plants between 15 cm and 2 m in height
DW	Small, woody plants less than 15 cm and all herbaceous plants
DR	Bryophytes, lichens, and ground cover

## **Environmental Parameters**

Physiographic section was determined from maps prepared by Wahrhaftig (1965). Elevation was determined from appropriate U.S. Geological Survey quadrangles. Slope gradient was determined in the field with a clinometer and aspect with a compass. Soil order, suborder, and associations were estimated from maps prepared by Rieger and others (1979). Soil particle size was estimated in the field and checked on selected plots by standard procedures (Black 1965). The depth to restrictive horizon was measured with a permafrost probe. The restrictive horizons were classed as either permafrost or gravel. Early season measurements of depth to permafrost were actually depths to seasonal frost. The percentage of coarse fragments was estimated at the time soil descriptions were taken. Landform was estimated on the plots and coded by standard forest survey codes. Rooting depth was measured at the soil pit and included 80 percent of all roots. Soil temperature was estimated at five points throughout each plot at three depths below the mineral soil-organic layer interface (1977 field season) or below the surface of the organic layer (1978 field season). Soil drainage was estimated and coded by standard forest survey codes. Thickness of the humus horizon was estimated at five points in each plot. Humus pH and carbon-nitrogen ratios were determined in the laboratory from five samples from selected plots; standard procedures were used (Black 1965). Mineral soil pH was determined by use of a field test kit.

Stand age was determined from increment cores taken from three to five dominant trees in each plot. Growth class or site class and site index were determined by Farr's (1967) tables for balsam poplar (*Populus balsamifera* L.), white spruce (*Picea glauca* (Moench) Voss), and black spruce; and those of Gregory and Haack (1965) for birch (*Betula papyrifera* Marsh.) and aspen (*Populus tremuloides* Michx.). Number of stems per hectare, basal area per hectare, and average stand diameter at breast height (d.b.h.) were calculated by use of standard forest measurement formulas. A metric version of Reineke's Stand Density Index (SDI) (1933) was calculated by the formula of Daniel and others (1979). Strata and ground coverage were calculated by adding the average cover value of each species in a stratum. Strata are defined as:

- A layer—trees over 5 m in height (A1, A2, A3)
- B layer—saplings, shrubs, and woody plants from 5 m to 15 cm (C, DH)
- C layer—small woody plants less than 15 cm and all herbaceous plants (B2, DW)
- D layer—mosses and lichens (DR)
- H layer—humus layer
- MS layer—mineral soil
- DW layer—decaying wood
- R&S layer—rocks and coarse fragments

## **Overstory Biomass and Production**

Sampling methods were similar to those described by Barney and others (1978). Only one plot was used for each stand. The stands were chosen to represent as broad a range of sites as possible. Fresh weights of samples were determined in the field with an autopsy balance to the nearest 10 g and with a spring balance to the nearest 2.3 kg. Subsamples of each crown third and the bole were returned to the laboratory for determination of fresh-to-dry-weight ratios. Samples were dried to constant weight at 65°C.

Crown subsamples were used to determine the ratios of foliage, branch wood, and current annual growth to total branch weight. Bole subsamples were used to determine wood, bark, and last-5-year-wood-increment weight ratios to the total bole sample weight.

A weighted least squares regression routine was used to determine the relationship between the component biomass and d.b.h., height, d.b.h. squared, and d.b.h. squared times height. The weighting variable was d.b.h. squared.

The derived equations for white and black spruce and birch were then used to determine standing biomass and annual production from tree data collected during the forest survey. Biomass and production equations for trembling aspen and balsam poplar were derived from unpublished data for the Fairbanks area.<sup>2/</sup> Biomass and production were determined for all trees with a d.b.h. of 2.54 cm and greater.

## **Statistical Analysis**

Initial classification runs were made on all stands 40 years of age and older by use of an indicator species analysis similar to that published by Hill and others (1975). The program used was TWINSPLAN (Hill 1979). Results were also used to develop a vegetative key to the described communities (see appendix).

SIMORD (Dick-Peddie and Moir 1970) was then used to check the within group similarities and to define the relationship between the environment and the vegetation. The final environment and vegetation tables<sup>3/</sup> were based on the results of the TWINSPLAN and SIMORD analyses. The final groups were named and compared with previously described plant communities in the preliminary classification for Alaska vegetation (Viereck and Dyrness 1980).

Finally, all stands less than 40 years old were classified by the procedures described above. The young communities were first compared with the older communities to determine if they represented a young phase of a previously described vegetative association. Similar communities were described separately to avoid confusion when trying to relate field conditions to the classification.

<sup>2/</sup> Personal communication from Keith Van Cleve, 1979, on file at the Forest Soils Laboratory, University of Alaska, Fairbanks, Alaska.

<sup>3/</sup> Klinka, K., J. P. Kimmins, J. T. Standish, and S. Phelps. Initial data synthesis in the synecological classification. Part 2. Environmental vegetation tables and a summary vegetation table by a computer program. Mimeoogr. 1977. 56 p. University of British Columbia, Vancouver, B.C. (Copies of the individual stand environment and vegetation tables are available from John Yarie, Forest Soils Laboratory, University of Alaska, Fairbanks, Alaska 99701.)

## Results—Vegetation Classification

A total of 365 plots were classified into 40 plant communities (table 1); 4 plots were of single unrelated types. Only summary tables of community vegetation (tables 2-6) and environment (tables 7 and 8) are presented. Individual stand tables for each community are available on request.<sup>4/</sup>

After the initial description the plant communities will be referred to by a code (table 1). The code contains the main overstory species:

- A—aspens
- BP—balsam poplar
- B—birch
- WS—white spruce
- BS—black spruce

A range of numeric designations indicate the canopy closure and community number: 1 to 9 for closed communities, 10 to 19 for open communities, and 20 plus for woodland communities (for example, WS1—closed white spruce community one). The letter Y before the community number indicates a young community (for example, WSY5—closed white spruce young community five). Therefore, communities WS5 and WSY5 are thought to be the same community with only minor differences in vegetation because of differences in average stand age.

### Closed Black Spruce Forests

***Picea mariana/Ledum palustre/Vaccinium vitis-idaea/Cladonia spp. (BS1).***—Overstory cover for this community averages 78 percent and is dominated by black spruce. Black spruce regeneration is abundant. The tall shrub layer is well developed with an average cover of 89 percent, although no species is consistently dominant. The low shrub layer is dominated by Labrador-tea (*Ledum palustre* L.)—14 percent cover; and bog blueberry (*Vaccinium uliginosum* L.)—15 percent. The herbaceous layer contains a number of species; the most prominent are mountain cranberry (*V. vitis-idaea* L.) and crowberry (*Empetrum nigrum* L.), with average cover of 24 and 27 percent, respectively. The moss and lichen layer is only moderately developed—average cover, 57 percent. It is dominated by *Hylocomium splendens* (Hedw.) B.S.G., *Cladonia* spp., and *Sphagnum* spp.

This community occurs at higher elevations in the Porcupine Plateau, on poorly drained to somewhat poorly drained Histic Pergelic Cryaquepts found on level and undulating plains. Elevation averages 414 m and ranges from 280 to 615 m. This community has been found in swamps and marshes with less canopy cover and along small, upland stream terraces. Average depth to permafrost is 33 cm, and the organic layer is 8 cm thick. The mineral soil is acid with an average pH of 5.8. Average stand age is 130 years.

The average number of stems greater than 2.5 cm d.b.h. is 3,608/ha; average d.b.h. is 6.0 cm. Reineke's (1933) SDI is 365. Stand biomass averages 2.4 kg/m<sup>2</sup>; the current annual increment (CAI) averages 35 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 37 g/yr.

This community was not described by Viereck and Dyrness (1980).

<sup>4/</sup> Request tables from John Yarie, Forest Soils Laboratory, University of Alaska, Fairbanks, Alaska 99701.

**Table 1—Community names and codes for Porcupine River drainage, interior Alaska**

Code 1/	Community
BS1; BSY1	<u>Picea mariana</u> / <u>Ledum palustre</u> / <u>Vaccinium vitis-idaea</u> / <u>Cladonia</u> spp.
BS2	<u>Picea mariana</u> / <u>Rosa acicularis</u> / <u>Equisetum</u> / <u>Cladonia rangiferina</u>
WSBS1	<u>Picea glauca</u> - <u>Picea mariana</u> / <u>Salix</u> spp./ <u>Arctostaphylos</u> spp.
WSBS2; WSBSY2	<u>Picea glauca</u> - <u>Picea mariana</u> / <u>Salix</u> spp./ <u>Vaccinium vitis-idaea</u> / <u>Hylocomium splendens</u>
WSBS3	<u>Picea glauca</u> - <u>Picea mariana</u> / <u>Salix</u> spp./ <u>Vaccinium vitis-idaea</u> / <u>Tichen</u>
WSBS4	<u>Picea mariana</u> - <u>Picea glauca</u> / <u>Salix</u> spp./ <u>Ledum palustre</u> / <u>Empetrum nigrum</u>
WSBSY5	<u>Picea mariana</u> - <u>Picea glauca</u> / <u>Salix</u> spp./ <u>Potentilla fruticosa</u> / <u>Rubus arcticus</u> - <u>Arctostaphylos</u> spp.
WS1	<u>Picea glauca</u> / <u>Rosa acicularis</u> - <u>Shepherdia canadensis</u> / <u>Linnaea borealis</u>
WS2	<u>Picea glauca</u> / <u>Alnus</u> spp./ <u>Arctostaphylos uva-ursi</u>
WSY2	<u>Picea glauca</u> / <u>Mertensia</u> sp./ <u>Gramineae</u>
WS3	<u>Picea glauca</u> / <u>Shepherdia canadensis</u> / <u>Arctostaphylos</u> spp./ <u>Peltigera</u> spp.
WS4	<u>Picea glauca</u> / <u>Rosa acicularis</u> / <u>Equisetum</u> spp.
WS5	<u>Picea glauca</u> / <u>Shepherdia canadensis</u> / <u>Equisetum</u> sp.- <u>Arctostaphylos</u> spp.
WSY5	<u>Picea glauca</u> / <u>Shepherdia canadensis</u> - <u>Rosa acicularis</u> / <u>Arctostaphylos</u> spp.- <u>Equisetum</u>
WS6	<u>Picea glauca</u> / <u>Alnus crispa</u> / <u>Rosa acicularis</u> / <u>Arctostaphylos rubra</u>
WS7	<u>Picea glauca</u> / <u>Rosa acicularis</u> - <u>Shepherdia canadensis</u> / <u>Arctostaphylos rubra</u> - <u>Linnaea borealis</u>
BS10	<u>Picea mariana</u> / <u>Arctostaphylos rubra</u> - <u>Empetrum nigrum</u> / <u>Cladonia</u> spp.
BS11	<u>Picea mariana</u> / <u>Betula nana</u> - <u>Potentilla fruticosa</u> / <u>Carex</u> spp.
BSY11	<u>Picea mariana</u> / <u>Betula nana</u> / <u>Carex</u> spp.
BS12	<u>Picea mariana</u> / <u>Alnus crispa</u> / <u>Betula nana</u> / <u>Vaccinium</u> spp./ <u>Cladonia</u> spp.
BS13	<u>Picea mariana</u> / <u>Vaccinium uliginosum</u> / <u>Empetrum nigrum</u> / <u>lichen</u>
BSY13	<u>Picea mariana</u> / <u>Vaccinium uliginosum</u> / <u>Arctostaphylos rubra</u> / <u>Dicranum</u> sp.
BSY14	<u>Picea mariana</u> / <u>Salix</u> / <u>Potentilla fruticosa</u> / <u>Arctostaphylos rubra</u> / <u>Peltigera</u> spp.
WSBS10	<u>Picea glauca</u> - <u>Picea mariana</u> / <u>Vaccinium uliginosum</u> / <u>Arctostaphylos rubra</u> / <u>Dicranum</u> sp.

1/ A = aspen; BP = balsam poplar; B = birch; WS = white spruce; BS = black spruce; Y = young community; 1 to 9 = closed community; 10 to 19 = open community; >20 = woodland community.

**Table 1—Community names and codes for Porcupine River drainage, interior Alaska, continued**

Code 1/	Community
WSBSY10	<u>Picea mariana</u> - <u>Picea glauca</u> / <u>Betula nana</u> / <u>Arctostaphylos rubra</u> - <u>Vaccinium uliginosum</u>
WSBS11	<u>Picea mariana</u> - <u>Picea glauca</u> / <u>Ledum palustre</u> / <u>Petasites spp.</u> / <u>Dicranum sp.</u>
WSBSY12	<u>Picea mariana</u> - <u>Picea glauca</u> / <u>Shepherdia canadensis</u> / <u>Epilobium spp.</u> / <u>Peltigera spp.</u>
WS10	<u>Picea glauca</u> / <u>Salix bebbiana</u> / <u>Rosa acicularis</u> / <u>Equisetum sp.</u> - <u>Epilobium sp.</u> / <u>lichen</u>
WS11	<u>Picea glauca</u> / <u>Salix</u> / <u>Shepherdia canadensis</u> / <u>Vaccinium vitis-idaea</u>
WSY11	<u>Picea glauca</u> / <u>Salix</u> / <u>Ledum palustre</u> / <u>Vaccinium vitis-idaea</u>
BS20	<u>Picea mariana</u> / <u>Betula nana</u> / <u>Eriophorum spp.</u> / <u>Sphagnum spp.</u>
BS21	<u>Picea mariana</u> / <u>Salix</u> / <u>Hylocomium splendens</u> - <u>Cladonia rangiferina</u>
A1	<u>Populus tremuloides</u> / <u>Salix spp.</u> / <u>Drepanocladus sp.</u>
BP1	<u>Populus balsamifera</u> / <u>Alnus</u> - <u>Salix</u> / <u>Rosa acicularis</u> / <u>Equisetum</u>
BPY1	<u>Populus balsamifera</u> / <u>Rosa acicularis</u> / <u>Equisetum sp.</u> - <u>Pyrola spp.</u>
BP2	<u>Populus balsamifera</u> / <u>Arctostaphylos uva-ursi</u> / <u>Peltigera spp.</u>
ABP1; ABPY1	<u>Populus tremuloides</u> - <u>Populus balsamifera</u> / <u>Rosa acicularis</u>
ABY1	<u>Populus tremuloides</u> - <u>Betula papyrifera</u> / <u>Rosa acicularis</u> / <u>Arctostaphylos uva-ursi</u> / <u>lichen</u>
A10	<u>Populus tremuloides</u> / <u>Salix spp.</u> / <u>Arctostaphylos uva-ursi</u> / <u>Graminae</u>
AY10	<u>Populus tremuloides</u> / <u>Salix spp.</u> / <u>Arctostaphylos uva-ursi</u> -- <u>Epilobium spp.</u>
AWS1; AWSY1	<u>Populus tremuloides</u> - <u>Picea glauca</u> / <u>Salix</u> / <u>Epilobium</u>
AWS2; AWSY2	<u>Populus tremuloides</u> - <u>Picea glauca</u> / <u>Salix</u> / <u>Arctostaphylos uva-ursi</u>
ABSY1	<u>Populus tremuloides</u> - <u>Picea mariana</u> / <u>Salix</u> / <u>Rosa acicularis</u> / <u>Equisetum sp.</u>
ABSY2	<u>Populus tremuloides</u> - <u>Picea mariana</u> / <u>Salix</u> / <u>Lupinus spp.</u>
WSB1	<u>Picea glauca</u> - <u>Betula papyrifera</u> / <u>Alnus</u> - <u>Salix</u> / <u>Galium boreale</u>
WSBY1	<u>Picea glauca</u> - <u>Betula papyrifera</u> / <u>Salix</u> / <u>Epilobium spp.</u>
BSBY1	<u>Picea mariana</u> - <u>Betula papyrifera</u> / <u>Arctostaphylos uva-ursi</u> / <u>lichen</u>
BSBY2	<u>Picea mariana</u> - <u>Betula papyrifera</u> / <u>Ledum palustre</u> / <u>Vaccinium vitis-idaea</u>
ABSY10	<u>Populus tremuloides</u> - <u>Picea mariana</u> / <u>Vaccinium uliginosum</u> / <u>Polytrichum sp.</u>

1/ A = aspen; BP = balsam poplar; B = birch; WS = white spruce; BS = black spruce; Y = young community; 1 to 9 = closed community; 10 to 19 = open community; >20 = woodland community.

**Table 2—Average cover and constancy of selected species in communities dominated by mature black spruce<sup>1/</sup>**

Layer and species <sup>2/</sup>	BS1	BS2	BS10	BS11	BS12	BS13	WSBS1	WSBS2	WSBS3	WSBS4	WSBS10	WSBS11	BS20	BS21
Percent														
A1:														
<i>Picea mariana</i>	78(100)	44( 80)	60(100)	32( 82)	44(100)	20( 87)	64( 50)		62(100)	73(100)	20( 50)	31(100)	9( 50)	19(100)
<i>Picea glauca</i>	18( 50)	1( 20)	17( 46)			7( 50)	6( 75)	20(100)	11( 60)	27( 50)	4( 30)	14( 50)	1( 25)	
<i>Betula papyrifera</i>	1( 40)	2( 20)		2( 17)										1( 25)
<i>Populus tremuloides</i>	1( 20)	1( 13)										9( 20)		
<i>Populus balsamifera</i>														
A2:														
<i>Picea mariana</i>		30( 50)												
<i>Picea glauca</i>		1( 20)		4( 9)			3( 13)	46( 25)	28(100)	19( 20)			6( 20)	
<i>Betula papyrifera</i>		1( 10)					8( 13)	13( 38)	41(100)	9( 20)				
<i>Populus tremuloides</i>									+ ( 17)					
<i>Populus balsamifera</i>									+ ( 17)					
B2:														
<i>Picea mariana</i>	24(100)	21( 90)	24(100)	19( 91)	27(100)	19( 88)	16( 88)	18( 83)	23(100)	24(100)	17( 80)	21(100)	13(100)	7(100)
<i>Picea glauca</i>	2( 20)	3( 30)	+ ( 7)	3( 36)	+ ( 17)	1( 50)	2( 63)	8( 93)	3( 60)	10( 50)	6(100)	4( 50)	1( 25)	
<i>Betula papyrifera</i>	1( 40)	+ ( 7)	+ ( 9)	6( 50)			2( 13)	+ ( 17)				2( 50)	2(100)	
<i>Populus tremuloides</i>	1( 10)	+ ( 7)										2( 40)		
<i>Populus balsamifera</i>		+ ( 10)							1( 17)					
C:														
<i>Salix arbusculoides</i>	8( 40)	3( 10)	2( 13)	2( 27)	10( 50)			2( 33)	6( 40)	10( 50)	1( 20)	10( 50)		
<i>Salix alaxensis</i>	18( 20)					3( 18)					6( 20)			
<i>Salix bebbiana</i>		18( 40)	7( 27)	1( 9)	20( 67)			8( 67)	1( 20)					
<i>Salix scouleriana</i>		1( 20)				2( 17)			+ ( 17)	8( 40)			3( 25)	
<i>Salix glauca</i>						4( 18)		18( 13)	6( 33)	3( 20)			22( 75)	
<i>Alnus crispa</i>	1( 20)	18( 50)	14( 40)	+ ( 9)	39( 83)	11( 38)	21( 38)	4( 33)		1( 25)	2( 20)	7( 25)	4( 50)	
<i>Betula nana</i>	18( 20)		7( 13)					4( 17)					18( 25)	
<i>Salix spp.</i>		2( 20)				2( 17)	19( 63)	23( 1)		23(100)		3( 25)	9( 50)	20(100)
DH:														
<i>Rosa acicularis</i>	8( 50)	18(100)	6( 73)	3( 18)	17( 83)	1( 25)	2( 13)	4( 67)	3( 80)	1( 50)	1( 20)	2( 75)		3( 25)
<i>Shepherdia canadensis</i>	4( 20)	15( 13)		+ ( 17)		2( 13)	9( 33)	13( 80)			1( 20)	4( 50)		
<i>Ledum palustre</i>	18(100)	1( 7)	5( 46)	4( 17)	19( 88)					22(100)	2( 20)	21(100)		
<i>Vaccinium uliginosum</i>	19( 80)	2( 20)	10( 40)	10( 55)	1( 17)	24( 88)		10( 50)	42( 75)	29(100)	8( 50)	2( 50)		
<i>Potentilla fruticosa</i>	2( 10)	1( 13)	11( 73)		1( 38)			3( 33)	3( 40)	4( 50)	11( 80)	4( 50)	4( 50)	
<i>Viburnum edule</i>	1( 10)							5( 25)			2( 20)			
<i>Juniperus communis</i>	1( 10)							2( 17)			2( 25)	13( 60)	3( 25)	40(100)
<i>Betula nana</i>						16( 82)	12( 67)	23( 75)	22( 50)	1( 20)	1( 25)	19( 60)	13(100)	12( 25)
<i>Ledum spp.</i>		7( 33)	7( 36)			4( 25)	21( 63)	4( 17)	8( 40)				27( 50)	
DW:														
<i>Arctostaphylos rubra</i>	14( 60)	1( 20)	18( 80)	13( 91)	17( 67)	14( 88)	35(100)	12(100)	18( 80)	18( 75)	17(100)	26(100)	9( 50)	
<i>Arctostaphylos uva-ursi</i>	14( 40)	1( 7)	1( 9)			1( 25)	25( 88)	4( 33)			1( 40)	2( 25)		24( 75)
<i>Vaccinium vitis-idaea</i>	24( 80)	10( 60)	21( 73)	12( 55)	23( 83)	18( 88)		18(100)	21(100)	21(100)	18( 80)	15(100)	11(100)	19( 75)
<i>Empetrum nigrum</i>	27( 80)	6( 30)	18( 80)	4( 18)	7( 33)	20( 88)	41( 88)	18( 83)	15( 80)	38(100)	18( 80)	14( 75)		24( 75)
<i>Equisetum spp.</i>	18( 80)	3( 33)	5( 73)	12( 83)	2( 50)	22( 75)		4( 33)		17(100)	2( 40)	1( 25)		
<i>Linnaea borealis</i>	15( 60)				4( 17)			12( 67)	2( 60)		4( 40)	1( 25)		
<i>Petasites sp.</i>	3( 40)	+ ( 10)	+ ( 7)	5( 82)	2( 33)	2( 50)	18( 25)	+ ( 17)	1( 20)	1( 50)		4(100)	1( 50)	
<i>Rubus chamaemorus</i>					2( 36)		1( 25)	+ ( 17)						
<i>Epilobium angustifolium</i>	1( 20)	+ ( 13)	3( 18)	2( 33)	+ ( 12)			+ ( 17)	1( 20)			1( 25)		
<i>Rubus arcticus</i>	8( 20)	1( 10)	+ ( 7)	1( 27)	2( 17)		2( 25)	4( 17)		1( 25)	1( 60)		14( 75)	9( 50)
<i>Pyrola spp.</i>		3( 27)	1( 27)	6( 67)	1( 25)	9( 38)	1( 50)	2( 40)	1( 25)	1( 20)	14( 75)			
<i>Geocaulon lividum</i>	6( 60)	1( 7)	+ ( 9)	* ( 17)			1( 17)	3( 60)		2( 40)	1( 25)			
<i>Carex spp.</i>					28(100)	7( 33)	24( 88)			1( 20)		4( 50)		
DR:														
<i>Hylocomium splendens</i>	18( 60)	54( 90)	22( 73)	20( 64)	13( 50)	11( 50)	23( 63)	32(100)	29( 80)	8( 50)	21(100)	23(100)	46( 75)	
<i>Cladonia rangiferina</i>	11( 60)	15( 90)	17( 47)	2( 36)	4( 33)	7( 25)	41( 75)	2( 33)	13( 80)	19(100)	20( 80)	1( 25)	33( 75)	
<i>Cladonia spp.</i>	40( 20)	4( 40)	18( 80)	2( 36)	13( 83)	14( 62)	17( 75)	6( 33)	4( 60)		3( 60)	2( 50)	5( 25)	
<i>Peltigera spp.</i>	8( 20)	8( 60)	7( 46)	4( 18)	20( 67)	2( 50)	11( 63)	2( 33)	7( 60)	2( 50)	1( 20)	3( 75)	9( 50)	12( 25)
<i>Cetraria spp.</i>	8( 40)	2( 60)	1( 27)	1( 36)	3( 67)	* ( 13)	15( 88)	1( 50)	3( 60)		1( 20)	2( 75)		
<i>Dicranum spp.</i>	18( 20)	3( 40)	20( 53)	3( 36)	8( 33)	4( 25)	6( 50)	6( 50)	10( 60)		23(100)	22(100)		
<i>Polytrichum sp.</i>		2( 20)	+ ( 7)	1( 9)										
<i>Drepanocladus sp.</i>	8( 20)	2( 10)	5( 13)	3( 18)	12( 50)			+ ( 17)	1( 40)					
<i>Sphagnum spp.</i>	13( 20)			3( 27)	4( 17)	2( 25)		+ ( 17)				1( 25)	44( 50)	3( 25)
<i>Aulacomnium sp.</i>		+ ( 10)	3( 7)	17( 64)	10( 33)	17( 38)	24( 88)	+ ( 17)	1( 20)	28( 75)	9( 60)	6( 25)		
<i>Pterozonium spp.</i>	6( 30)	2( 13)			+ ( 17)	4( 13)				2( 25)				
<i>Tomentypnum nitens</i>	1( 10)	1( 9)	6( 55)	20( 50)	7( 25)			1( 33)	4( 40)	3( 25)	4( 20)		1( 25)	
<i>Ptilidium ciliare</i>								8( 50)	13( 80)					

1/ Constancy is shown in parentheses; + = less than 1 percent cover. BS = black spruce; WS = white spruce; 1 to 9 = closed community; 10 to 19 = open community; >20 = woodland community.

2/ A1 = dominant and codominant trees; A2 = intermediate trees; B2 = tree seedlings; C = shrubs between 2 and 10 m in height; DH = shrubs and woody plants between 15 cm and 2m in height; DW = small, woody plants less than 15 cm tall and all herbaceous plants; DR = bryophytes, lichens, and ground cover.

**Table 3—Average cover and constancy of selected species in communities dominated by mature white spruce<sup>1/</sup>**

Layer and species <sup>2/</sup>	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS10	WS11
<u>Percent</u>									
A1:									
<i>Picea glauca</i>	49(100)	78(100)	58( 84)	88(100)	60(100)	43(100)	65(100)	38(100)	41(100)
<i>Picea mariana</i>			+ ( 17)						
<i>Populus tremuloides</i>	1( 13)		1( 33)				12( 25)	8( 20)	1( 17)
<i>Populus balsamifera</i>		2( 43)	+ ( 17)	8( 50)	4( 21)				
<i>Betula papyrifera</i>		18( 29)			+ ( 7)				
A2:									
<i>Picea glauca</i>	75( 25)				+ ( 7)	63( 75)			2( 17)
<i>Picea mariana</i>									4( 17)
<i>Populus tremuloides</i>	5( 13)				+ ( 7)				
<i>Populus balsamifera</i>					+ ( 7)				
<i>Betula papyrifera</i>						1( 25)			
B2:									
<i>Picea glauca</i>	18(100)	7(100)	16(100)			21(100)	10(100)	21(100)	14(100)
<i>Picea mariana</i>	1( 13)					4( 25)			3( 33)
<i>Populus tremuloides</i>	4( 25)		4( 50)			1( 14)		1( 25)	2( 20)
<i>Populus balsamifera</i>		1( 14)				2( 36)	2( 50)	1( 25)	
<i>Betula papyrifera</i>	5( 25)	4( 43)							2( 20)
C:									
<i>Salix arbusculoides</i>	8( 25)						14( 50)	17( 80)	18( 33)
<i>Salix alaxensis</i>						3( 7)			4( 17)
<i>Salix scouleriana</i>	12( 38)		1( 17)			1( 7)		3( 25)	2( 20)
<i>Salix bebbiana</i>	7( 38)							22( 80)	
<i>Salix glauca</i>	1( 13)		2( 17)				12( 25)	13( 40)	4( 17)
<i>Salix</i> spp.	18( 13)	27( 86)	8( 67)		34( 93)	23( 50)	7( 50)		32( 67)
<i>Alnus crispa</i>	22( 25)	28( 58)			2( 14)	14( 75)		18( 40)	8( 17)
<i>Alnus tenuifolia</i>		6( 14)				4( 7)			
<i>Alnus sinuata</i>		12( 29)							
DH:									
<i>Rosa acicularis</i>	4(100)	42(100)	3( 50)	75(100)	17( 71)	4(100)	21(100)	12(100)	19( 83)
<i>Shepherdia canadensis</i>	10( 88)	6( 14)	19(100)	2( 50)	19( 71)		26(100)	4( 40)	19(100)
<i>Potentilla fruticosa</i>	1( 25)				2( 21)	18( 25)	7( 50)	2( 40)	11( 33)
<i>Viburnum edule</i>	1( 13)	4( 29)			4( 14)	1( 25)		12( 40)	
<i>Vaccinium vitiginosum</i>	8( 13)								
<i>Cornus stolonifera</i>		6( 29)				2( 21)		1( 25)	3( 20)
DW:									
<i>Limnaea borealis</i>	2( 88)	4( 29)	7( 67)		6( 43)	15( 50)	20(100)	11( 80)	18( 33)
<i>Mertensia</i> spp.	2( 75)	3( 58)	4( 67)	2( 50)	6( 57)	2( 25)	4( 75)	1( 20)	5( 33)
<i>Gaultheria boreale</i>	2( 25)	4( 29)	1( 33)	4( 50)	4( 43)		1( 25)	1( 20)	1( 33)
<i>Epilobium angustifolium</i>	3( 50)	+ ( 14)	1( 33)		3( 29)	2( 25)	4( 50)	12( 60)	
<i>Arctostaphylos rubra</i>	8( 63)		12(100)		14( 64)	9( 75)	23(100)	12( 60)	22( 83)
<i>Arctostaphylos uva-ursi</i>	7( 38)	8( 58)	13( 83)		18( 64)		6( 50)	6( 40)	8( 50)
<i>Geocaulon lividum</i>	12( 63)	+ ( 14)			3( 50)	4( 25)	19( 50)	2( 40)	
<i>Vaccinium vitis-idaea</i>	2( 25)		+ ( 17)			26( 75)	12( 25)	18( 60)	25(100)
<i>Pyrola</i> spp.	1( 25)	3( 43)	+ ( 17)		2( 50)	13( 50)	8( 75)	18( 40)	13( 67)
<i>Equisetum</i> spp.		20( 58)	1( 33)	75(100)	18( 71)	8( 25)	18( 75)	17(100)	24( 67)
DR:									
<i>Hylocomium splendens</i>	27( 88)	17( 57)	9( 33)		3( 7)	13( 50)	39(100)	21( 40)	25( 67)
<i>Cetraria</i> spp.	2( 88)		+ ( 17)			4( 50)	3( 80)	8(100)	
<i>Parmelia</i> spp.	2(100)		+ ( 17)			9(100)	4(100)	18( 33)	
<i>Drepanocladus</i> spp.	10( 88)	2( 14)	6( 50)		2( 7)	12( 25)	2( 40)	+ ( 17)	
<i>Peltigera</i> spp.	7( 75)		6( 67)		+ ( 7)	12(100)	3( 60)	20( 83)	
<i>Cladonia</i> spp.	18( 88)		4( 33)		2( 14)	2( 25)	1( 25)	4( 60)	28( 83)
<i>Rhytidiodelphus</i> spp.	7( 50)							4( 40)	9( 17)
<i>Ptilidium ciliare</i>	4( 38)		+ ( 17)					2( 20)	
<i>Pleurozium</i> spp.	3( 25)	2( 17)	8( 50)			18( 25)			1( 17)
<i>Dicranum</i> spp.	8( 25)	15( 14)	1( 33)		+ ( 7)	40( 25)		2( 40)	+ ( 17)
<i>Polytrichum</i> spp.	2( 25)							+ ( 20)	
<i>Tomentypnum nitens</i>	1( 13)		+ ( 17)				3( 25)		+ ( 20)
Moss						50( 71)			

1/ Constancy is shown in parentheses; + = less than 1 percent cover; WS = white spruce; 1 to 9 = closed community; 10 to 19 = open community.

2/ A1 = dominant and codominant trees; A2 = intermediate trees; B2 = tree seedlings; C = shrubs between 2 and 10 m in height; DH = shrubs and woody plants between 15 cm and 2m in height; DW = small, woody plants less than 15 cm tall and all herbaceous plants; DR = bryophytes, lichens, and ground cover.

**Table 4—Average cover and constancy of selected species in communities dominated by young conifers<sup>1/</sup>**

Layer and species <sup>2/</sup>	BSY1	WSBSY2	WSBSY5	WSY2	WSY5	BSY11	BSY13	BSY14	WSBSY10	WSBSY12	WSY11
<u>Percent</u>											
A1:											
<i>Picea mariana</i>	18( 69)	10( 50)	63(100)	+ ( 10)		3( 56)	10( 71)		3( 25)		
<i>Picea glauca</i>	1( 13)	17( 83)	18( 60)	6( 70)	18( 67)	+ ( 11)	2( 14)	1( 33)	1( 25)		1( 33)
<i>Betula papyrifera</i>	1( 31)	2( 33)			+ ( 10)					2( 20)	+ ( 17)
<i>Populus tremuloides</i>	3( 13)		3( 20)	+ ( 10)	1( 13)			4( 33)		3( 40)	+ ( 17)
<i>Populus balsamifera</i>			1( 20)	+ ( 10)	+ ( 7)						
B2:											
<i>Picea mariana</i>	21(100)	19( 83)	23(100)	+ ( 10)	+ ( 13)	7(100)	22(100)	35(100)	26(100)	23(100)	
<i>Picea glauca</i>	1( 38)	18(100)	3( 40)	18(100)	19(100)	1( 56)	2( 57)	4( 33)	3( 75)	18(100)	19(100)
<i>Betula papyrifera</i>	2( 50)	3( 33)	1( 20)	4( 30)	+ ( 13)	1( 22)	1( 14)	3( 67)		6( 40)	18( 67)
<i>Populus tremuloides</i>	3( 44)	2( 33)	1( 40)	2( 30)	1( 40)	1( 33)	1( 14)	17( 33)		18( 80)	7( 50)
<i>Populus balsamifera</i>	+ ( 6)	2( 33)	1( 20)	+ ( 10)	1( 27)	1( 33)		2( 33)		6( 80)	
C:											
<i>Salix alaxensis</i>	1( 6)		18( 60)		1( 7)			9( 33)			4( 17)
<i>Salix arbusculoides</i>	8( 32)	23(100)			1( 13)			4( 33)	7( 50)	26( 60)	21( 67)
<i>Salix beddoiana</i>			37( 60)		15( 40)	4( 22)		2( 33)	7( 25)	18( 60)	19( 67)
<i>Salix scouleriana</i>	1( 6)				3( 33)			2( 33)		21( 80)	
<i>Salix glauca</i>	2( 6)	50(100)	19( 60)		4( 20)	6( 22)		9( 33)		28( 60)	7( 7)
<i>Alnus crispa</i>	16( 38)		23( 60)	8( 30)	1( 13)	+ ( 11)	4( 29)			14( 20)	17( 33)
<i>Betula nana</i>	9( 19)					7( 33)	2( 14)				7( 17)
<i>Betula glandulosa</i>	3( 6)		6( 20)								
<i>Salix</i> spp.				52( 90)	19( 33)		4( 43)				2( 33)
DH:											
<i>Ledum palustre</i>	18( 69)	+ ( 17)	9( 20)	+ ( 10)	2( 26)	13( 33)	10( 57)	9( 33)	7( 50)	6( 40)	10( 50)
<i>Vaccinium uliginosum</i>	20( 63)	2( 17)	20( 60)		+ ( 7)	6( 33)	23( 86)	9( 33)			8( 33)
<i>Rosa acicularis</i>	7( 56)	15(100)	2( 80)	9( 60)	8( 87)	+ ( 11)		19( 67)	2( 25)	6( 80)	1( 33)
<i>Potentilla fruticosa</i>	1( 25)	7( 33)	2( 80)		9( 47)	2( 33)	2( 43)	20(100)	4( 75)	6( 40)	+ ( 17)
<i>Shepherdia canadensis</i>		50(100)	2( 60)	18( 60)	19( 87)			9( 33)		18(100)	+ ( 17)
<i>Betula nana</i>						50(100)			24(100)	19( 40)	
DW:											
<i>Vaccinium vitis-idaea</i>	15( 75)	20(100)	5( 60)	1( 30)	3( 13)	7( 89)	16( 43)	14( 67)	14( 75)	2( 20)	18( 50)
<i>Arctostaphylos rubra</i>	10( 44)	21(100)	4( 80)		22( 87)	2( 44)	14(100)	18(100)	15(100)	3( 60)	1( 33)
<i>Arctostaphylos uva-ursi</i>	2( 6)	29( 83)	13( 80)	4( 30)	10( 80)		1( 14)	1( 33)		1( 60)	4( 33)
<i>Eptilobium</i> sp.	2( 50)	8( 67)	1( 20)	1( 30)	4( 60)	1( 33)	+ ( 14)	18(100)	1( 25)	7( 80)	1( 33)
<i>Empetrum nigrum</i>	6( 38)	15( 67)			1( 13)	4( 33)	13( 86)	2( 33)	2( 50)		
<i>Petasites</i> spp.	4( 25)	+ ( 17)			1( 20)	1( 13)	1( 33)	+ ( 14)	4( 33)	1( 25)	1( 20)
<i>Rubus arcticus</i>	2( 19)		2( 80)	1( 20)	4( 33)	1( 33)				1( 25)	1( 33)
<i>Rubus chamaemorus</i>	3( 25)					1( 22)		2( 33)	4( 50)		+ ( 17)
<i>Geocaulon lividum</i>	2( 13)	+ ( 17)			1( 13)	1( 22)				1( 20)	
<i>Linnaea borealis</i>	+ ( 6)	6( 33)	1( 40)	1( 20)	7( 40)		8( 43)	4( 33)		3( 75)	1( 20)
<i>Pyrola</i> spp.	2( 38)	3( 50)	1( 40)	4( 30)	1( 40)	4( 44)	1( 29)	1( 33)	1( 25)	1( 20)	1( 33)
<i>Mertensiana</i> spp.	4( 67)				4( 60)		1( 22)	1( 33)			
<i>Equisetum</i> spp.	10( 67)	1( 60)	11( 40)	10( 73)	2( 44)	2( 59)	1( 33)	6( 50)	1( 40)	1( 20)	+ ( 17)
<i>Galium boreale</i>		1( 20)	1( 30)	1( 40)	+ ( 11)	49( 89)	9( 43)	9( 33)			4( 17)
<i>Carex</i> spp.						19( 67)					
DR:											
<i>Hylocomium splendens</i>	2( 25)	4( 17)	10( 40)	22( 30)		1( 11)	4( 43)	14( 67)	3( 75)		
<i>Cladonia rangiferina</i>	2( 31)	+ ( 17)	6( 40)	+ ( 10)	1( 27)		7( 43)				
<i>Cladonia</i> spp.	12( 69)	23( 83)	15( 60)	+ ( 10)	1( 20)	14( 56)	6( 71)	14( 71)	18( 50)	1( 20)	6( 50)
<i>Peltigera</i> spp.	11( 63)	21( 83)	9( 80)	3( 20)	12( 33)	4( 78)	2( 59)	15(100)	11( 75)	19(100)	+ ( 33)
<i>Cetraria</i> spp.		1( 33)	6( 20)		1( 40)	3( 11)		2( 67)		1( 60)	+ ( 17)
<i>Dicranum</i> spp.	2( 19)		6( 40)	+ ( 10)	+ ( 7)	3( 11)	19( 86)		4( 50)	1( 20)	10( 50)
<i>Polytrichum</i> spp.	11( 19)				+ ( 13)	9( 44)				1( 60)	21( 17)
<i>Drepanocladus</i> spp.	1( 13)		5( 60)	+ ( 10)	4( 13)	4( 33)				2( 20)	4( 17)
<i>Sphagnum</i> spp.	7( 31)					9( 56)	4( 29)				
<i>Aulacomnium</i> sp.	1( 13)		13( 60)		1( 13)	18( 56)	6( 14)				
<i>Pleurozium</i> spp.					+ ( 7)			1( 33)		1( 20)	
<i>Tomentypnum nitens</i>			19( 40)		2( 13)						4( 17)
<i>Rhytidadelphus</i> sp.	12( 67)	6( 20)									

1/ Constancy is shown in parentheses; + = less than 1 percent cover; BS = black spruce; WS = white spruce; Y = young community; 1 to 9 = closed community; 10 to 19 = open community.

2/ A1 = dominant and codominant trees; B2 = tree seedlings; C = shrubs between 2 and 10 m in height; DH = shrubs and woody plants between 15 cm and 2 m in height; DW = small, woody plants less than 15 cm tall and all herbaceous plants; DR = bryophytes, lichens, and ground cover.

**Table 5—Average cover and constancy of selected species in communities of mature deciduous and mixed conifer-deciduous trees<sup>1/</sup>**

Layer and species <sup>2/</sup>	A1	BP1	BP2	ABP1	A10	AWS1	AWS2	WSB1
<u>Percent</u>								
A1:								
<u>Picea glauca</u>				10( 33)	1( 50)	21( 83)	25( 63)	29(100)
<u>Picea mariana</u>								
<u>Populus tremuloides</u>	71(100)		21( 50)	68(100)	50(100)	49(100)	13( 88)	
<u>Populus balsamifera</u>	2( 33)	88(100)	29(100)	13(100)	1( 25)	3( 33)	2( 38)	
<u>Betula papyrifera</u>	21( 33)				1( 25)	+ ( 17)	4( 25)	29(100)
A2:								
<u>Picea glauca</u>				1( 50)			18( 38)	
<u>Picea mariana</u>								
<u>Populus tremuloides</u>				2( 50)			6( 25)	
<u>Populus balsamifera</u>				12( 50)			1( 13)	
<u>Betula papyrifera</u>								
B2:								
<u>Picea glauca</u>	3(100)	6( 40)	2(100)	6( 33)	2( 25)	9(100)	12(100)	1( 50)
<u>Picea mariana</u>	1( 33)							
<u>Populus tremuloides</u>	8(100)		10(100)	12(100)	11(100)	4( 83)	6( 75)	
<u>Populus balsamifera</u>	2( 57)	4( 60)	5(100)	3( 67)		4( 43)	2( 25)	
<u>Betula papyrifera</u>						1( 17)	+ ( 13)	2( 50)
C:								
<u>Salix glauca</u>	18( 67)					10( 33)	1( 13)	4( 50)
<u>Salix bebbiana</u>						4( 33)		1( 50)
<u>Alnus crispa</u>	3( 33)	8( 40)					1( 13)	45(100)
<u>Alnus tenuifolia</u>		27( 60)						
<u>Salix alaxensis</u>		19( 60)					1( 13)	
<u>Salix spp.</u>			2(100)	42( 67)	25(100)	+ ( 17)	8( 63)	
<u>Salix scouleriana</u>						10( 33)	1( 13)	
DH:								
<u>Rosa acicularis</u>	14(100)	21(100)	2(100)	10(100)	5(100)	6(100)	5( 88)	19(100)
<u>Sneezeweed canadensis</u>	21( 67)	15( 60)	10(100)	33( 67)	10(100)	29( 83)	12( 88)	
<u>Vaccinium uliginosum</u>	1( 33)						1( 13)	13( 50)
<u>Ledum palustre</u>	6( 33)						2( 13)	
<u>Viournum edule</u>		6( 80)					1( 13)	8( 50)
<u>Potentilla fruticosa</u>		1( 20)	1( 50)			3( 17)		1( 50)
DW:								
<u>Equisetum spp.</u>	2( 67)	28(100)		1( 33)	1( 25)	+ ( 17)	2( 38)	9(100)
<u>Arctostaphylos uva-ursi</u>	18( 67)		15(100)		47(100)	1( 33)	5( 63)	4( 50)
<u>Arctostaphylos rubra</u>	1( 33)	6( 20)	1( 50)		1( 50)	4( 50)	5( 38)	
<u>Calamagrostis canadensis</u>	3( 33)	4( 40)		10( 33)		+ ( 17)	8( 25)	13( 50)
<u>Epilobium angustifolium</u>	1( 33)	2( 40)	2(100)	2( 33)	1( 50)	4( 83)	2( 50)	2( 50)
<u>Linnæa borealis</u>	1( 33)	1( 20)	8( 50)		2( 50)	10( 67)	2( 38)	1( 50)
<u>Pyrola spp.</u>	2(100)	1( 40)				4( 50)	+ ( 25)	1( 50)
<u>Empetrum nigrum</u>	1( 33)				1( 25)		4( 50)	
<u>Gaulia spp.</u>	1( 33)	2( 60)	1( 50)	2( 33)	2( 75)	1( 33)	2( 38)	1(100)
<u>Vaccinium vitis-idaea</u>	1( 33)				1( 25)		+ ( 13)	4( 50)
<u>Mertensia spp.</u>		2( 40)	1( 50)	8( 67)	2( 75)	2( 67)	2( 63)	1( 50)
<u>Geocaulon lividum</u>		1( 20)						1( 50)
DR:								
<u>Drepanocladus spp.</u>	2( 67)					7( 33)	2( 25)	2(100)
<u>Cladonia spp.</u>	1( 33)		1( 50)		1( 25)	2( 50)	6( 75)	4(100)
<u>Cetraria spp.</u>		1( 20)				1( 50)	+ ( 13)	2( 50)
<u>Polytrichum spp.</u>	1( 33)							
<u>Rhytidiodelphus spp.</u>								
<u>Pleurozium spp.</u>	1( 33)	1( 20)					1( 13)	1( 50)
<u>Peltigera spp.</u>	1( 33)		2(100)			5( 83)	6( 88)	2( 50)
<u>Cladonia rangiferina</u>	1( 33)							1( 50)
<u>Hylocomium splendens</u>	3( 33)		1( 50)			8( 50)	3( 25)	
<u>Litter</u>	50( 67)	85(100)					10( 25)	
<u>Dicranum spp.</u>				10( 33)			7( 25)	4( 50)
<u>Autacomium sp.</u>							2( 13)	1( 50)

<sup>1/</sup>Constancy is shown in parentheses; + = less than 1 percent cover. A = aspen; BP = balsam poplar; WS = white spruce; B = birch; 1 to 9 = closed community; 10 to 19 = open community.

<sup>2/</sup>A1 = dominant and codominant trees; A2 = intermediate trees; B2 = tree seedlings; C = shrubs between 2 and 10 m in height; DH = shrubs and woody plants between 15 cm and 2 m in height; DW = small, woody plants less than 15 cm tall and all herbaceous plants; DR = bryophytes, lichens, and ground cover.

**Table 6—Average cover and constancy of selected species in communities of young deciduous and mixed conifer-deciduous trees<sup>1/</sup>**

Layer and species 2/	BPY1	ABPY1	ABY1	AY10	AWSY1	AWSY2	ABSY1	ABSY2	WBSY1	BSBY1	BSBY2	ABSY10
<u>Percent</u>												
<b>A1:</b>												
<i>Picea glauca</i>	1( 25)	+ ( 14)		2( 29)	5( 75)	1( 15)	1( 25)	1( 33)	1( 20)	1( 20)	1( 20)	1( 20)
<i>Picea mariana</i>				1( 25)	+ ( 7)		22( 75)	1( 33)		31(100)	15( 50)	
<i>Populus tremuloides</i>		15( 50)		31(100)	43( 88)	31( 52)	40(100)	? ( 57)			3( 10)	21(100)
<i>Populus balsamifera</i>	23( 75)		1( 25)	1( 21)	4( 50)	5( 39)	1( 25)					
<i>Betula papyrifera</i>			4( 50)			+ ( 8)	5( 75)		17( 10)	3(100)	5( 40)	
<b>A2:</b>												
<i>Picea glauca</i>					4( 14)	1( 13)				2( 20)		
<i>Picea mariana</i>												
<i>Populus tremuloides</i>					4( 14)	5( 13)						
<i>Populus balsamifera</i>					+ ( 7)	1( 13)						
<i>Betula papyrifera</i>												
<b>B2:</b>												
<i>Picea glauca</i>	4( 75)	+ ( 14)	2( 25)	4( 71)	3(100)	4( 5)	1( 50)	7( 57)	10( 30)	2( 20)	2( 20)	1( 50)
<i>Picea mariana</i>	2( 25)		19(100)	+ ( 7)			13(100)	13(100)	22(100)	21(100)	5(100)	
<i>Populus tremuloides</i>	3( 50)	18( 35)	5( 38)	19(100)	11( 38)	15( 72)	9(100)	7( 57)	4( 10)	2( 20)	2( 30)	10(100)
<i>Populus balsamifera</i>	4( 50)	2( 57)	1( 38)	1( 29)	7( 50)	4( 51)	5( 50)	2( 67)			1( 10)	
<i>Betula papyrifera</i>			2( 38)		+ ( 13)	1( 15)	2(100)	1( 33)	12(100)	2( 40)	2( 60)	
<b>C:</b>												
<i>Salix glauca</i>				8( 25)			5( 54)	27( 75)		21( 80)	11( 60)	
<i>Salix novae-anglica</i>											2( 10)	13( 50)
<i>Salix bebbiana</i>	11( 25)	4( 14)	8( 50)	4( 11)		5( 30)	5( 37)	8( 50)		8( 50)	5( 60)	10( 50)
<i>Alnus crispa</i>	19( 50)		15( 53)	+ ( 7)			27( 75)		3( 40)	13( 40)	18( 60)	1( 10)
<i>Alnus tenuifolia</i>												
<i>Salix alaxensis</i>				+ ( 13)			1( 8)		1( 20)			
<i>Salix spp.</i>	43( 75)	10( 71)			10( 57)	33( 83)			53(100)		5( 30)	
<i>Salix scouleriana</i>			9( 50)	+ ( 7)			1( 23)		4( 40)			
<i>Salix arborescens</i>			+ ( 13)				2( 15)		6( 50)	2( 10)	1( 50)	
<b>DH:</b>												
<i>Rosa acicularis</i>	13( 75)	10(100)	12(100)	8( 71)	18( 75)	1( 43)	6(100)	6( 67)	5( 80)	5( 40)	5( 50)	13(100)
<i>Shepherdia canadensis</i>	2( 25)	15( 71)	10( 75)	22( 33)	22( 75)	1( 85)	1( 25)	1( 33)	11( 40)	1( 10)		11(100)
<i>Vaccinium uliginosum</i>				1( 7)				2( 33)				
<i>Ledum palustre</i>	11( 25)			3( 25)				1( 25)		4( 40)	11( 60)	
<i>Viburnum edule</i>									1( 20)			
<i>Potentilla fruticosa</i>						1( 7)		1( 50)	10( 67)			
<b>DW:</b>												
<i>Equisetum spp.</i>	15( 75)	2( 29)	3( 75)	2( 43)	5( 33)	2( 31)	3( 75)	5( 33)	13(100)	10( 30)	3( 50)	4( 50)
<i>Arctostaphylos uva-ursi</i>	3( 25)	2( 29)	15( 33)	13( 33)	2( 13)	6( 54)	7( 25)	2( 33)		5( 30)	8( 40)	21( 50)
<i>Arctostaphylos rubra</i>			4( 50)	2( 14)	2( 13)	2( 33)	5( 50)	21( 57)	4( 50)		11( 500)	
<i>Calamagrostis canadensis</i>			4( 13)	9( 14)	3( 25)	2( 23)			12( 40)	1( 20)	2( 10)	
<i>Epilobium angustifolium</i>	3( 25)	13( 36)	2( 50)	4( 71)	6( 38)	3( 69)	2(100)	6( 57)	11(100)	3( 30)	3( 50)	11(100)
<i>Linnæa borealis</i>		2( 14)	4( 63)	1( 7)	2( 25)	2( 39)	5( 50)	2( 33)				
<i>Pyrola spp.</i>	19( 75)		+ ( 13)	2( 14)	1( 25)	1( 23)	1( 25)	1( 57)	1( 20)	1( 20)	2( 40)	
<i>Mertensia spp.</i>	1( 25)		2( 33)	2( 64)	2( 50)	6( 52)	1( 25)	2( 33)	5(100)	1( 50)	1( 30)	9( 50)
<i>Geocaulon lividum</i>			+ ( 14)	1( 13)			1( 7)		1( 20)	1( 20)		
<i>Gallium spp.</i>	1( 25)	4( 43)			2( 64)	4( 75)	3( 54)	1( 25)		1( 20)	1( 20)	
<i>Vaccinium vitis-idaea</i>	1( 25)		2( 38)	1( 7)		2( 15)	3( 50)	2( 50)	4( 50)		32( 60)	24(100)
<i>Empetrum nigrum</i>			+ ( 13)				1( 50)	2( 33)	2( 20)		6( 50)	5(100)
<i>Lupinus spp.</i>									19(100)			5(100)
<i>Carex spp.</i>												
<b>DR:</b>												
<i>Orepanocladus spp.</i>				4( 38)		4( 38)	2( 15)	5( 50)	1( 20)	1( 40)	2( 10)	
<i>Cladonia spp.</i>	6( 25)		8( 88)	+ ( 7)		1( 23)	5( 50)	1( 33)	2( 40)	10( 60)	15( 90)	23( 50)
<i>Cetraria spp.</i>	3( 25)		2( 63)			1( 31)	2( 50)	1( 33)	1( 40)	4( 60)	3( 60)	1( 50)
<i>Polytrichum spp.</i>			1( 25)			+ ( 15)			2( 40)		3( 20)	53(100)
<i>Rhytidiodelphus spp.</i>			2( 38)						2( 20)			
<i>Pleurozium spp.</i>							1( 25)					50( 13)
<i>Peltigera spp.</i>	6( 25)		10( 88)	1( 21)	1( 25)	4( 46)	10( 75)	24( 57)	7( 40)	13( 80)	8( 80)	
<i>Cladonia rangiferina</i>			+ ( 13)			+ ( 7)	1( 25)		1( 20)	5( 60)		
<i>Hylocomium splendens</i>	23( 50)			2( 7)			4( 25)		3( 20)		4( 50)	
<i>Litter</i>						31( 62)	33( 75)		11( 20)	4( 20)		
<i>Moss</i>		2( 57)		2( 21)		6( 38)		5( 50)				
<i>Aulacomnium sp.</i>			1( 13)				1( 25)		1( 25)		1( 20)	5( 40)
<i>Dicranum spp.</i>						2( 13)	+ ( 7)	1( 25)		4( 40)		+ ( 10)
<i>Sphagnum spp.</i>											2( 20)	

<sup>1/</sup>Constancy is shown in parentheses; + = less than 1 percent cover. BP = balsam poplar; A = aspen; Y = young community; 1 to 9 = closed community; 10 to 19 = open community.

<sup>2/</sup>A1 = dominant and codominant trees; A2 = intermediate trees; B2 = tree seedlings; C = shrubs between 2 and 10 m in height; DH = shrubs and woody plants between 15 cm and 2 m in height; DW = small, woody plants less than 15 cm tall and all herbaceous plants; DR = bryophytes, lichens, and ground cover.

**Table 7—Environmental summary of the mature plant associations in Porcupine Plateau and Yukon Flats**

Item	BP1	BP2	AI	ABP1	AWS1	AWS2	WSB1	WS1	WS2	WS3	WS4	WS5	WS6	WS7
Physiographic section: 1/														
Elevation	YF 139	YF 177	YF 180	YF 137	YF 160	YF 186	YF 357	YF 213	YF 201	YF 182	YF 152	YF 146	YF 215	YF 194
Slope	0	0	1	0	0	3	18	2	1	2	0	1	1	0
Aspect	0	0	0	0	0	0	45	0	0	0	0	0	0	0
Soil order and suborder 2/	EF	IR	IQ	EF	EF	EF	IR	EF	EF	IR	EF	EF	EF	EF
Soil association	2	1	2	2	2	2	1	2	2	1	2	2	2	2
Depth to permafrost (cm)	144	130	109	74	87	89	32	78	87	69	125	67	59	80
Landform 3/	FP	FL	FL		FL		ST	FP	FL	FP	FL		ST	
Rooting depth (cm)	50	23	58	23	32	29	25	35	32	27	20	23	31	45
Soil temperature:														
5 cm	17	9	14	13	10	13	17	12	10	12	11	7	10	
10 cm	14	8	9	10	7	10	11	4	7	9	8	4	7	
20 cm	10	7	8	8	5	8	8	6	5	7	6	2	5	
Soil drainage class 4/	4	4	5	4	4	4	4	5	5	4	4	4	4	4
Thickness of organic matter (cm)	5	5	5	7	6	5	5	5	5	1	7	10	11	
pH of humus														
C/N of humus														
pH of mineral soil	25		22		24	25		26	22	28		22		
Age (yr)	8.0	7.0	6.9	6.0	6.4	6.8		6.9	6.9	7.1	6.5	7.2	6.5	7.0
Growth class and site index: 5/														
White spruce	6-65	6-21	8-36	6-62	7-53	7-61	7-56	6-64	7-50	6-71	6-59	7-57	7-51	7-61
Black spruce														
Birch														
Aspen														
Balsam poplar	6-74	8-34	8-39	8-28			6-44							
Stems/ha (2.5+ cm)	1,479	4,219	4,137	6,175	4,206	4,408	4,136	4,333	1,073	4,501	1,018	2,248	3,012	2,182
Basal area (m <sup>2</sup> /ha)	21.1	9.7	13.0	9.9	18.2	14.1	8.4	22.9	21.5	19.9	33.2	18.5	17.4	19.3
D.b.h. (cm)	14.3	5.4	7.1	4.6	8.4	7.1	13.4	9.4	17.1	7.8	17.8	10.2	8.4	11.0
Biomass (kg/m <sup>2</sup> )	8.1	3.1	4.2	2.6	6.0	4.4	3.6	8.2	9.4	6.1	15.8	6.8	6.1	6.9
CAI per year (g/m <sup>2</sup> )	290	113	133	86	258	258	276	803	1026	418	2206	720	614	651
Stratum cover (percent):														
A layer	102	71	97	91	97	77	60	100	92	94	72	76	96	86
B layer	100	6	60	93	65	34	115	44	79	33	107	78	71	68
C layer	51	34	40	65	45	59	54	45	33	54	75	81	53	122
D layer	15	2	6	38	32	46	21	79	41	48	4	65	67	62
Ground cover:														
Humus	74		76		46	46		21	18	63	41	30		
Mineral soil														

A blank means value could not be determined.

1/ YF = Yukon Flats; PP = Porcupine Plateau.

2/ EF2 = Typic Cryofluents-Histic Pergelic Cryaquepts, loamy, nearly level association; IR1 = Typic Cryochrepts, loamy, nearly level to rolling associations; IR2 = Typic Cryocrepts Typic Cryorthents, loamy, nearly level to rolling association; IQ = Aquept; IQ2 = Histic Pergelic Cryaquepts, loamy nearly level to rolling association; IQ6 = same as IQ2 with Pergelic Cryofibrists, nearly level association; IQ9 = Histic Pergelic Cryaquepts-Typic Cryocrepts, loamy, nearly level to rolling association.

3/ FP = floodplain; FL = flatwoods; ST = stream terraces; LP = level and undulating uplands; RP = rolling and hilly plains, plateaus and uplands; SM = swamps and marshes.

4/ 2 = poorly drained; 3 = somewhat poorly drained; 4 = moderately well drained; 5 = well drained.

5/ The 1st value represents the growth class, the 2d the site index (for example, BP2--6-65 = a growth class of 6 and a white spruce or balsam poplar site index of 65). Growth classes (per year): 9 = 0 to 0.7 m<sup>3</sup>/ha; 8 = 0.71 to 0.98 m<sup>3</sup>/ha; 7 = 0.99 to 1.33 m<sup>3</sup>/ha; 6 = 1.34 to 3.43 m<sup>3</sup>/ha.

**Table 7—continued**

BS1	BS2	WSBS1	WSBS2	WSBS3	WSBS4	A10	WS10	WS11	BS10	BS11	BS12	BS13	WSB10	WSB11	BS20	BS21	
PP 414	YF 308	PP 421	YF 321	PP 214	YF 397	PP 187	YF 214	YF 220	PP 307	PP 433	PP 381	PP 417	PP 500	PP 361	PP 211	YF 445	
1 170	9 214	2 144	9 88	2 0	5 113	1 0	4 0	0 0	1 0	6 222	3 102	4 219	11 98	8 236	0 0	5 63	
IQ 9	IR 2	IQ 9	IQ 2	IQ 6	IQ 6	EF 2			IQ 9	IQ 9	IQ 9	IQ 9	IQ 9	IQ 9	IQ 9	IQ 10	
28	62	24	56	61	18	74	92	73	40	30	56	27	42	58	46	20	
LP	RP	RP	RP	LP			LP		RP	LP	RP	RP	RP	RP	SM	RP	
	34	25	18	25		23	27	29	22	27	24	30	40	28		17	
17	7		3	7	11	10	19	12	7	12	7	13	19	6			
12	3		2	4	6	9	15	8	4	7	4	8	14	3			
1	2		1	3	1	7	11	3	2	3	3	2	7	2			
3	4	3	4	5	2	5	1	4	3	3	4	2	3	2	3	3	
8	10	6	9	9	11	3	9	8	8	9	8	6	9	16	33	5	
	4.7							5.4		5.9			5.6				
5.8	43	34	35	74	35	35		27	34	27		28	28	32			
	5.4	6.8	6.8	7.0	6.8	6.1	7.8	6.5	6.5	6.7	6.3	6.7	7.0	6.3	6.0	6.4	
104	84	107	106	89	106	45	111	74	100	109	68	72	147	63	50	86	
9-26	7-52 8-35	8-37 9-30	8-43 9-38	8-45 9-26		7-61	7-51	8-52	7-48 8-36 7-35	9-30 8-41 9-23	8-56 8-41 9-23	8-38 9-27 9-20	9-34	7-58 8-40		8-29	
						9-29											
2,635	4,876	2,789	4,207	4,520	2,748	4,476	1,960	3,442	3,900	1,766	1,807	1,197	1,688	2,464	223	2,135	
6.7	21.7	7.2	12.5	15.2	6.9	5.0	12.1	12.6	9.6	5.0	5.0	3.2	4.4	4.2	0.3	6.8	
5.8	8.0	6.0	6.3	6.2	5.7	4.9	10.9	7.0	5.6	6.1	6.2	5.4	5.6	5.1	2.1	6.4	
1.7	6.3	2.0	4.0	4.1	1.8	2.0	4.5	3.8	2.6	1.4	1.4	0.9	1.2	1.2	0.1	1.8	
27	208	70	285	131	44	67	468	257	49	74	26	34	58	30	1	34	
55	69	55	72	78	85	53	53	51	59	43	37	27	31	35	9	16	
89	67	132	44	35	89	58	86	90	65	69	95	106	87	74	138	77	
69	75	172	78	100	105	73	106	138	69	88	141	67	72	80	76	79	
57	96	146	58	78	72	5	47	68	76	48	36	62	67	72	94	105	
18	24		8	18								18					

**Table 8—Environmental summary of the young plant associations in Porcupine Plateau and Yukon Flats**

Item	BPY1	ABPY1	ABY1	AWSY1	AWSY2	ABSY1	ABSY2	WSBY1	BSBY1	BSBY2	WSY2	WSY5
Physiographic section 1/												
Elevation (m)	YF 217	YF 139	PP 256	YF 150	YF 157	PP 347	PP 222	YF 226	PP 397	PP 352	YF 258	YF 178
Slope	2	0	1	0	0	13	9	1	15	7	3	0
Aspect	0	0	0	0	0	250	155	0	298	197	0	0
Soil order and suborder 2/	EF 2	IR 2	IR 1	IR 1	IQ 9	IQ 9	IQ 9	IQ 9	IQ 9	IQ 9	IR 25	IR 1
Soil association												
Depth to permafrost (cm)	78	105	100	98	110	90	83	94	58	60	56	93
Landform 3/	FP	FP		FL	FP	RP		FL	RP	RP	RP	FL
Rooting depth (cm)	25	25	31	31	34	37		23	30	30	22	28
Soil temperature:												
5 cm	12	14	15	11	15		12	11	16	12	10	13
10 cm	8	11	12	9	11		10	9	11	7	7	8
20 cm	5	9	10	7	9		7	8	7	4	5	7
Soil drainage class 4/	2	4	5	4	4	5	4	4	5	4	4	4
Thickness of organic matter (cm)	6	3	0	4	3	4	4	6	3	9	8	6
pH of humus						6.5					7.4	6.3
C/N of humus				23	21			21			15	26
pH of mineral soil	7.1	7.1	6.0	7.1	7.1	6.0	6.3	6.0	6.0	6.6	6.4	6.9
Age (yr)	22	10	23	23	13	23	22	13	25	23	22	22
Growth class and site index : 5/												
White spruce	7-68	6-62	9-42	6-71	6-69	6-75		7-66	7-64	7-55	6-52	7-53
Black spruce			9-31		8-35	6-69	9-	9-34	9-37	9-34		
Birch			7-41					6-	9-28	7-16		
Aspen			7-28	3-41	6-44	7-44	5-58	7-50				
Balsam poplar	8-38	6-34										9-
Stems/ha (2.5+ cm)	510	11	1,334	4,282	2,582	5,864	445	567	1,379	1,187	731	728
Basal area (m <sup>2</sup> /ha)	1.2	.31	2.5	9.0	4.3	10.2	.4	1.0	2.3	1.5	2.1	1.7
D.b.h. (cm)	1.3	.5	3.3	4.2	4.4	5.3	3.0	2.7	5.2	4.5	7.4	4.9
Biomass (kg/m <sup>2</sup> )	.5	0	.6	2.5	1.3	2.7	.1	.3	.7	.5	.6	.5
CAI per year (g/m <sup>2</sup> )	13	0	2	99	39	92	3	?1	22	28	39	30
Stratum cover (percent):												
A layer	25	0	20	74	37	71	3	18	41	25	16	16
B layer	98	56	33	37	56	74	93	83	55	94	95	75
C layer	42	69	80	56	73	65	95	105	97	110	34	79
D layer	30	20	39	14	19	32	39	45	39	46	52	47
Ground layer:												
Humus		53	19		52	45		63	18		63	29
Mineral soil					19			8				

A blank means the value could not be determined.

1/ YF = Yukon Flats; PP = Porcupine Plateau.

2/ EF2 = Typic Cryoflyents Histic Pergelic Cryaquepts, loamy, nearly level association; IR1 = Typic Cryochrepts, loamy, nearly level to rolling association; IR2 = Typic Cryochrepts-Typic Cryorthents, loamy, nearly level to rolling association; IQ = Aquept; IQ2 = Histic Pergelic Cryaquepts, loamy, nearly level to rolling association; IQ6 = same as IQ2 with Pergelic Cryofibrists, nearly level association; IQ9 = Histic Pergelic Cryaquepts, loamy, nearly level to rolling association.

3/ FP = flood plain; FL = flatwoods; ST = stream terraces; LP = level and undulating uplands; RP = rolling and hilly plains, plateaus and uplands; SM = swamps and marshes.

4/ 2 = poorly drained; 3 = somewhat poorly drained; 4 = moderately well drained; 5 = well drained.

5/ The 1st value represents the growth class, and the 2d value the site index (for example, BP2--6-65 = a growth class of 6 and a white spruce or balsam poplar site index of 65). Growth classes (per year): 9 = 0 to 0.7 m<sup>3</sup>/ha; 8 = 0.71 to 0.98 m<sup>3</sup>/ha; 7 = 0.99 to 1.33 m<sup>3</sup>/ha; 6 = 1.34 to 3.43 m<sup>3</sup>/ha.

**Table 8—Environmental summary of the young plant associations in Porcupine Plateau and Yukon Flats, continued**

A blank means the value could not be determined.

1/ YF = Yukon Flats; PP = Porcupine Plateau.

Z/EF2 = Typic Cryoflyents-Histic Pergelic Cryaquepts, loamy, nearly level association; IRI = Typic Cryochrepts, loamy, nearly level to rolling association; IR2 = Typic Cryochrepts-Typic Cryorthents, loamy, nearly level to rolling association; IQ Aquept; IQ<sup>2</sup> = Histic Pergelic Cryaquepts, loamy, nearly level to rolling association, I<sub>b</sub><sup>2</sup> = same as IQ<sup>2</sup> with Pergelic Cryofibrists, nearly level association; IO<sup>2</sup> = Histic Pergelic Cryaquepts, loamy, nearly level to rolling association.

3/ FP = flood plain; FL = flatwoods; ST = stream terraces; LP = level and undulating uplands; RP = rolling and hilly plains, plateaus and uplands; SM = swamps and marshes.

4/ 2 = poorly drained; 3 = somewhat poorly drained; 4 = moderately well drained; 5 = well drained.

5/ The 1st value represents the growth class, and the 2d value the site index (for example, BP2-6-65 = a growth class of 6 and a white spruce or balsam poplar site index of 65). Growth classes (per year): 9 = 0 to 0.7 m<sup>3</sup>/ha; 8 = 0.71 to 0.98 m<sup>3</sup>/ha; 7 = 0.99 to 1.33 m<sup>3</sup>/ha; 6 = 1.34 to 3.43 m<sup>3</sup>/ha.

**Picea mariana/Ledum palustre/Vaccinium vitis-idaea/Cladonia spp. (BSY1).**—This association has an overstory cover of 19 percent. The major tree reproduction is black spruce. White spruce is a common associate. The tall shrub layer is only moderately developed and is composed of several species of willow. Major species in the low shrub layer are Labrador-tea and bog blueberry with average cover values of 15 and 23 percent. Rose (*Rosa acicularis* Lindl.) is a common associate. The major species in the herbaceous layer is mountain cranberry, with average cover of 12 percent. The moss and lichen layer is dominated by species of *Peltigera* and *Cladonia*.

This community is found almost exclusively in the Porcupine Plateau section of the unit at an average elevation of 376 m. It is predominantly an upland community, for the most part on level and undulating uplands and rolling and hilly plains. It occurs mainly on Histic Pergelic Cryaquepts and Typic Cryochrepts. Soil drainage ranged from one very poorly drained site to somewhat excessively drained sites. Average thickness of the humus layer is 6 cm. The mineral soil is acid—mean pH 6.0. Average stand age is 22 years.

The average number of stems greater than 2.5 cm in d.b.h. is 646/ha. Average d.b.h. is 3.9 cm, and Reineke's (1933) SDI is 33. Stand biomass and CAI average 0.3 kg/m<sup>2</sup> and 9 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 7.1 g/yr.

The stands in this young community will mature into either a BS1 or a BS2 community type. The primary determining factor will be soil drainage. Poorly drained to somewhat poorly drained plots will become BS1, whereas moderately well-drained to excessively well-drained plots should become BS2 community types.

**Picea mariana/Rosa acicularis/Equisetum/Cladonia rangiferina (BS2).**—Overstory cover for this community averages 73 percent and ranges from 37 to 91 percent. The major overstory species is black spruce. Common associates include paper birch and white spruce. The most abundant tree regeneration is black spruce. The tall shrub layer frequently contains American green alder (*Alnus crispa* (Ait.) Pursh.) and bebb willow (*Salix bebbiana* Sarg.), with an average cover of 24 and 32 percent, respectively. The most consistently occurring low shrub is rose with an average cover of 12 percent. All other species occur in less than 20 percent of the stands. The major genus found in the herbaceous layer is *Equisetum*, with a cover value of 16 percent. Mountain-cranberry, geocaulon (*Geocaulon lividum* (Richards.) Fern.), and twinflower (*Linnaea borealis* L.) are frequent associates, with a cover of about 8 percent. The moss and lichen layer is dominated by *Hylocomium splendens* which has an average cover of 50 percent. Associated species include *Cladonia rangiferina* (L.) Web. and *Peltigera* spp., with an average cover of 9 and 8 percent, respectively.

This community occurs throughout the southern half of both the Yukon Flats and Porcupine Plateau sections, predominantly on rolling and hilly plains. Some examples of this community type have been reported in the mountains and in swamps and marshes. The latter was found with a greatly reduced canopy coverage. Elevation averages 308 m and ranges from 183 to 262 m. The community occurs mainly on moderately well-drained to well-drained Typic Cryochrepts with an average depth to permafrost of 65 cm. Average rooting depth is 34 cm, and the organic layer is 10 cm thick. The mineral soil is acid, with an average pH of 5.4. The average age of the overstory is 88 years.

The number of stems greater than 2.5 cm in d.b.h. averages 5,272/ha. Average d.b.h. is 8.2 cm, and Reineke's (1933) SDI is 881. Overstory biomass and CAI average 6.8 kg/m<sup>2</sup> and 222 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 9.4 g/yr.

This community is similar to the *Picea mariana/Rosa acicularis/Peltigera* community described by La Roi (1967) and Foote (see footnote 1, p. 3). It should probably be considered a northern phase of that community type. This community also differs from the BS1 type in that it is generally found in locations with better drainage—either on sloping terrain or in warmer soils with good drainage. As a result, the CAI is about 10 times greater than in the BS1 community type.

#### **Closed White Spruce-Black Spruce Forests**

***Picea glauca-Picea mariana/Salix spp./Arctostaphylos spp. (WSBS1).***—The over-story cover of this community averages 61 percent and ranges from 37 to 88 percent. The dominant overstory species are white spruce and black spruce. The dominant tree reproduction is black spruce, but white spruce is common. Paper birch is rare. The tall shrub layer consists of willow (*Salix* L.) and alder (*Alnus* Mill.). Willow is dominant, with an average cover of 23 percent. The low shrub layer is moderately developed and contains, among other species, Labrador-tea, dwarf arctic birch (*Betula nana* L.), and *Vaccinium* spp. with average cover of 21, 22, and 27 percent, respectively. The herbaceous layer is well developed and is dominated by both red-fruit bearberry (*Arctostaphylos rubra* (Rehd. & Wilson) Fern.) and bearberry (*A. uva-ursi* (L.) Spreng.), with average cover of 35 and 25 percent. A common associate is crowberry—cover value, 41 percent. The moss and lichen layer is dominated by *Aulacomnium* sp. and *Cetraria* spp., with a cover value of 24 and 15 percent, respectively. Common associates are Cyperaceae, *Parmelia* spp., and *Cladonia* spp.

This community is found at higher elevations in the Porcupine Plateau section, predominantly on somewhat poorly drained to very poorly drained Histic Pergelic Cryaquepts on either hilly and rolling plains or in swamps and marshes. Elevation averages 421 m and ranges from 282 to 533 m. Depth to permafrost averages 24 cm, and the organic layer is 6 cm thick. The mineral soil is nearly neutral; average pH, 6.8. The average stand age is 114 years.

The average number of stems greater than 2.5 cm in d.b.h. is 3,110/ha. Average d.b.h. is 6.1 cm, and Reineke's (1933) SDI is 323. Stand biomass averages 2.2 kg/m<sup>2</sup>; the CAI, 78 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 9.7 g/yr.

This community was not described by Viereck and Dyrness (1980). It represents a high-elevation, poorly drained community where black spruce is close to its altitudinal and latitudinal limits.

**Picea glauca-Picea mariana/Salix spp./Vaccinium vitis-idaea/Hylocomium splendens (WSBS2).**—The overstory cover of this community averages 72 percent. The predominant overstory species are white spruce and black spruce. Tree reproduction is dominated by black spruce, although white spruce is common in the reproductive layer. The tall shrub layer is dominated by bebb willow; the low shrub layer, by rose and bog blueberry with an average cover value of 4 and 10 percent, respectively. Major species in the herbaceous layer are crowberry, mountain cranberry, and red-fruit bearberry with cover values of 18, 18, and 12 percent. Common associates are twinflower and winter-green (*Pyrola* L.). The moss and lichen layer is dominated by *Hylocomium splendens* with an average cover of 32 percent. Common associates are *Parmelia* spp., *Cetraria* spp., and *Dicranum* spp.

This community is scattered throughout the inventory unit but close to the boundary between the Yukon Flats and Porcupine Plateau. It is found in both sections on somewhat poorly drained to moderately well-drained Histic Pergelic Cryaquepts. Elevation averages 321 m and ranges from 175 to 487 m. Depth to permafrost averages 56 cm. The organic layer is 9 cm thick, and the mineral soil is slightly acid, with an average pH of 6.8. Stand age averages 106 years.

The number of stems greater than 2.5 cm in d.b.h. averages 4,207/ha. The average d.b.h. is 6.3 cm, and the Reineke (1933) SDI is 461. Stand biomass averages 4.0 kg/m<sup>2</sup>; CAI, 285 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 22.7 g/m<sup>2</sup>.

This community was not described by Viereck and Dyrness (1980). The community is found at lower elevations and on better drained sites than the WSBS1 community, which results in a greater abundance of white spruce and about three times greater CAI.

**Picea glauca-Picea mariana/Salix spp./Vaccinium vitis-idaea/Hylocomium splendens (WSBSY2).**—The overstory cover is 18 percent, predominantly white spruce and black spruce. The major tree reproduction is white and black spruce. The tall shrub layer is dominated by little tree willow (*Salix arbusculoides* Anders.) and grayleaf willow (*S. glauca* L.). The low shrub layer is dominated by buffaloberry (*Shepherdia canadensis* (L.) Nutt.) and rose, with average cover values of 50 and 15 percent. The major species found in the herbaceous layer are mountain cranberry, red-fruit bearberry, and bearberry with average cover values of 20, 21, and 29 percent, respectively. The moss and lichen layer is dominated by *Peltigera* spp. and *Cladonia* spp. with average cover values of 21 and 23 percent.

This community appears to be concentrated in the center of the area with scattered occurrences in other parts of Yukon Flats. Because of the proximity of several of the plots it is likely that one large fire about 1945 was responsible for the distribution of this community type. Elevation averages 223 m. The community occurs on moderately well-drained Histic Pergelic Cryaquepts. Depth to permafrost averages 106 cm and rooting depth 30 cm. The average thickness of the humus layer is 6 cm, and the mineral soil is basic with an average pH of 7.3. Stand age averages 27 years.

The number of stems greater than 2.5 cm in d.b.h. averages 781/ha; d.b.h., 3.8 cm. Reineke's (1933) SDI is 38. Stand biomass averages 0.5 kg/m<sup>2</sup> and CAI 30 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 19.5 g/yr.

This community may develop into a WSBS2. One major difference in the young community is in the moss and lichen layer where constancy and cover of *Hylocomium splendens* are very low.

***Picea glauca*-*Picea mariana*/*Salix* spp./*Vaccinium vitis-idaea*/Lichen (WSBS3).—** Total overstory cover for this community type averages 86 percent. The dominant over-story species is black spruce, but white spruce is a common associate. The major tree reproduction is black spruce, but again white spruce is a common associate. Willow species are dominant in the tall shrub layer. The low shrub layer is predominantly composed of buffaloberry and rose, with average cover values of 13 and 43 percent. The herbaceous layer is dominated by mountain cranberry, red-fruit bearberry, and crowberry; average cover values are 21, 18, and 15 percent, respectively. Geocaulon and twinflower are common associates. The moss and lichen layer is dominated by *Cladonia rangiferina*, *Ptilidium ciliare* (Web.) Hampe, and *Hylocomium splendens* with average cover values of 13, 13, and 25 percent.

This community occurs at an average elevation of 214 m at the eastern edge of the Yukon Flats portion of the unit. One stand was reported in the Porcupine Plateau but close to the Black River, at an average elevation of 397 m. This community occurs on well-drained Histic Pergelic Cryaquepts with an average depth to permafrost of 61 cm. Thickness of the organic layer averages 9 cm, and the mineral soil is neutral with an average pH of 7.0. The average stand age is 89 years.

The average number of stems greater than 2.5 cm in d.b.h. is 4,520/ha. The d.b.h. averages 6.2 cm, and Reineke's (1933) SDI is 482. Stand biomass and CAI average 4.1 kg/m<sup>2</sup> and 13 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 8.6 g/yr.

This community was not described by Viereck and Dyrness (1980). It appears to be similar to WSBS2, except for a lack of bog blueberry and a much greater dominance of black spruce in WSBS3.

***Picea mariana*-*Picea glauca*/*Salix* spp./*Ledum palustre*/*Empetrum nigrum* (WSBS4).—** Overstory cover for this community type averages 85 percent and is composed entirely of white spruce and black spruce. The majority of the tree reproduction is black spruce, but white spruce is a common associate. The tall shrub layer is dominated by several species of willow. The major species in the low shrub layer are Labrador-tea and bog blueberry, with average cover values of 22 and 42 percent. The herbaceous layer is dominated by mountain cranberry, *Equisitum*, and crowberry with average cover values of 21, 17, and 38 percent. The major species in the moss and lichen layer include *Cladonia rangiferina* and *Aulacomnium* sp., with average cover values of 19 and 28 percent.

This community occurs at relatively high elevations north of the Porcupine River within the Porcupine Plateau, at an average elevation of 397 m. It occurs on poorly drained Histic Pergelic Cryaquepts with an average depth to permafrost of 18 cm. Thickness of the humus layer averages 11 cm, and the mineral soil is slightly acid with an average pH of 6.8. The average stand age is 106 years.

The number of stems greater than 2.5 cm in d.b.h. averages 2,748/ha. D.b.h. averages 5.7 cm, and Reineke's (1933) SDI is 256. Stand biomass and CAI average 1.8 kg/m<sup>2</sup> and 44 g/m<sup>2</sup> per year. The CAI of basal area averages 7.9 g/cm<sup>2</sup> per year.

This community was not described by Viereck and Dyrness (1980).

**Picea mariana-Picea glauca/Salix spp./Potentilla fruticosa/Rubus arcticus-Arctostaphylos spp. (WSBSY5).**—Overstory cover for this community averages 66 percent. The major overstory species are black spruce and white spruce. Aspen and balsam poplar are rare associates. Tree reproduction is dominated by black spruce. The major species in the tall shrub layer are bebb willow, American green alder, and grayleaf willow. The low shrub layer is dominated by rose and bush cinquefoil (*Potentilla fruticosa* L.) with an average cover value of 2 percent each. The major species in the herbaceous layer are dewberry (*Rubus arcticus* L.), bearberry, and red-fruit bearberry with average cover values of 2, 3, and 10 percent. The moss and lichen layer is dominated by *Peltigera* spp. and *Cladonia* spp.

This community occurs throughout the inventory unit at an average elevation of 313 m. It occurs on poorly drained to well-drained Histic Pergelic Cryaquepts, from swamps and marshes to rolling and hilly uplands. Depth to permafrost averages 66 cm. The thickness of the humus layer averages 5 cm, and the mineral soil is slightly acid with a pH of 6.5. The average stand age is 33 years.

The average number of stems is 3,157/ha. D.b.h. averages 4.1 cm, and Reineke's (1933) SDI is 173. Stand biomass and CAI average 1.3 kg/m<sup>2</sup> and 39 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area is 9.0 g/yr.

Because this community is not related to any of the other closed white spruce-black spruce communities, it is not possible to predict the mature community type. It may represent a community that was not sampled in the mature stage.

#### Closed White Spruce Forests

**Picea glauca/Rosa acicularis-Shepherdia canadensis/Linnaea borealis (WS1).**—Total overstory cover averages 100 percent for this association. The dominant overstory species is white spruce. Aspen and paper birch are rarely found in the overstory. The majority of tree reproduction is white spruce. The tall shrub layer is dominated by various species of willow; the two most abundant are scouler willow (*Salix scouleriana* Barratt) and littletree willow. The low shrub layer is dominated by rose and buffaloberry, with an average cover of 4 and 10 percent. Several other shrub species can occur, but their constancy is generally less than 25 percent. The two major species in the herbaceous layer are twinflower and bluebells (*Mertensia paniculata* (Ait.) G. Don) with an average cover of 2 percent. Other commonly associated species are geocaulon and red-fruit bearberry. A total of 39 herbaceous species were reported for this community. The moss and lichen layer is dominated by *Parmelia* sp., *Hylocomium splendens*, and *Cladonia* spp. with an average cover of 2, 27, and 18 percent, respectively. The presence of *Parmelia* and *Usnea* sp. is associated with twig and branch litter fall.

This community occurs in the Yukon Flats section of the inventory unit, predominantly in upland areas away from the major rivers, although it can occur along stream terraces of the smaller streams. It is generally found on Typic Cryochrepts or Histic Pergelic Cryaquepts. Depth to permafrost averages 78 cm (range, 33 to 125 cm). The average rooting depth is 33 cm, and the organic layer is 5 cm thick. The mineral soil is neutral, with an average pH of 7.0. The average stand age is 74 years.

The number of stems greater than 2.5 cm in d.b.h. averages 4,333/ha. Diameter averages 9.4 cm, and Reineke's (1933) SDI is 902. Average biomass and CAI are 8.2 kg/m<sup>2</sup> and 803 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area is 35.1 g/yr.

This community appears to be a northern analog of the *Picea glauca/Linnaea borealis/Equisetum sylvaticum* community described by Foote (see footnote 1, p. 3). The presence of willow in this northern community differentiates it from its southern analog.

***Picea glauca/Alnus spp./Arctostaphylos uva-ursi* (WS2).**—Overstory cover of this community averages 92 percent. The overstory is comprised of white spruce with an occasional paper birch or balsam poplar. Tree reproduction is white spruce, but paper birch is a frequent associate. The tall shrub layer is dominated by willow species. American green alder is a very common associate, which may help explain the absence of buffaloberry in the low shrub layer. The low shrub layer, with an average cover of 42 percent, is dominated by rose. The herbaceous layer is weakly developed; *Equisetum* spp. are most abundant, with an average cover of 20 percent. Associated with *Equisetum* spp. are bearberry and *Mertensia* spp. The major moss species is *Hylocomium splendens*.

This community occurs at slightly higher elevations (average 201 m) than other white spruce communities. It can occur in both the Yukon Flats and Porcupine Plateau sections on landforms varying from flood plains of the major rivers to level and undulating uplands. The most commonly occurring soil associations are Typic Cryofluvents and Histic Pergelic Cryaquepts, nearly level to rolling and loamy. Depth to permafrost averages 86 cm and rooting depth 32 cm. The mineral soil is slightly acid, with an average pH of 6.9. Average stand age is 118 years.

The number of stems greater than 2.5 cm averages 1,073/ha; d.b.h., 17.1 cm. Reineke's (1933) SDI is 583. Stand biomass averages 9.4 kg/m<sup>2</sup>; CAI, 1,026 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 46.6 g/yr; the range is from 35.1 to 63.6.

This community was not described by Viereck and Dyrness (1980).

***Picea glauca/Mertensia sp./Graminae* (WSY2).**—This community has an overstory cover of 16 percent and is composed predominantly of white spruce. The principal reproducing tree species is white spruce, although aspen and birch can be found; balsam poplar and black spruce are rare. Even though willow is the primary tall shrub, alder is not uncommon and because of this, the community will probably mature into a WS2 type. At present, the primary low shrub is buffaloberry with an average cover of 18 percent. The primary species in the herbaceous layer are bluebells and equisetum with average cover values of 4 and 2 percent.

This type is scattered throughout the entire unit at an average elevation of 258 m. It is mainly found on Typic Cryofluvents or Histic Pergelic Cryaquepts with an average depth to permafrost of 66 cm. The average rooting depth is 22 cm, and the humus layer is quite thick with an average depth of 8 cm. The mineral soil is acid with an average pH of 6.4, and stand age averages 22 years.

The number of stems averages 731/ha; d.b.h., 7.4 cm. Reineke's (1933) SDI is calculated to be 104. Stand biomass averages 0.6 kg/m<sup>2</sup>; CAI, 39 g/m<sup>2</sup> per year. The CAI per square centimeter of basal averages 18.3 g/yr.

***Picea glauca/Shepherdia canadensis/Arctostaphylos spp./Peltigera spp. (WS3).***—

The overstory is dominated by white spruce with an average cover of 79 percent. Infrequently, balsam poplar, black spruce, and aspen are associates. The total overstory cover averages 94 percent. The tall shrub layer is dominated by willow with an average cover of 8 percent. Buffaloberry is the most common low shrub with an average cover of 12 percent. The most common herb is red-fruit bearberry with an average cover of 7 percent. Common associates are twinflower, *Mertensia* sp., and bearberry. The moss and lichen layer is relatively diverse; *Peltigera* spp. is most frequent, with an average cover of 6 percent.

This community occurs at relatively low elevations (182 m) in the Yukon Flats section, generally on or near flood plains on Typic Cryofluvents or Typic Cryochrepts. Depth to permafrost averages 69 cm; rooting depth, 27 cm. Mineral soil is neutral, with an average pH of 7.1. The average stand age is 81 years.

Number of stems averages 4,501/ha and d.b.h., 7.8 cm. Reineke's (1933) SDI is 694. The biomass of standing trees averages 6.1 kg/m<sup>2</sup>; CAI, 418 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 21.6 g/yr.

This community was not described by Viereck and Dyrness (1980).

***Picea glauca/Rosa acicularis/Equisetum spp. (WS4).***—Total overstory cover averages 93 percent and is almost completely dominated by white spruce. Balsam poplar is an associate but has a cover value of only 3 percent. Regeneration and a tall shrub layer were absent from this community. The low shrub layer is dominated by rose with an average cover of 75 percent. The herbaceous layer is dominated by *Equisetum* spp. with an average cover of 75 percent.

This community occupies flood plains of the major streams and rivers in the Yukon Flats section of the unit. Stands occur where there is frequent flooding and accumulation of silt. This accounts for the poor development of moss and lichens. The prevalent soil suborder is Typic Cryochrepts, and depth to permafrost averages 124 cm. Rooting depth appears to be shallow—only 25 cm. Average thickness of the organic layer is only 1 cm, and the mineral soil is slightly acid with an average pH of 6.5. The average stand age is 120 years.

The number of stems larger than 2.5 cm averages 1,129/ha; d.b.h., 23.7 cm. Reineke's (1933) SDI is 1036. Stand biomass averages 23.4 kg/m<sup>2</sup>; CAI, 3293 g/m<sup>2</sup> per year. The average CAI per square centimeter of basal area is 67.4 g/yr.

This community was not described by Viereck and Dyrness (1980). Its stability depends on the frequency of flooding and silt deposition. If the disturbance is not a regular occurrence, then this community represents a seral stage to one of the other white spruce flood plain communities.

***Picea glauca/Rosa acicularis/Equisetum spp. (WS4).***—Total overstory cover averages 93 percent and is almost completely dominated by white spruce. Balsam poplar is an associate but has a cover value of only 3 percent. Regeneration and a tall shrub layer were absent from this community. The low shrub layer is dominated by rose with an average cover of 75 percent. The herbaceous layer is dominated by *Equisetum* spp. with an average cover of 75 percent.

This community occupies flood plains of the major streams and rivers in the Yukon Flats section of the unit. Stands occur where there is frequent flooding and accumulation of silt. This accounts for the poor development of moss and lichens. The prevalent soil suborder is Typic Cryochrepts, and depth to permafrost averages 124 cm. Rooting depth appears to be shallow—only 25 cm. Average thickness of the organic layer is only 1 cm, and the mineral soil is slightly acid with an average pH of 6.5. The average stand age is 120 years.

The number of stems larger than 2.5 cm averages 1,129/ha; d.b.h., 23.7 cm. Reineke's (1933) SDI is 1036. Stand biomass averages 23.4 kg/m<sup>2</sup>; CAI, 3293 g/m<sup>2</sup> per year. The average CAI per square centimeter of basal area is 67.4 g/yr.

This community was not described by Viereck and Dyrness (1980). Its stability depends on the frequency of flooding and silt deposition. If the disturbance is not a regular occurrence, then this community represents a seral stage to one of the other white spruce flood plain communities.

***Picea glauca/Shepherdia canadensis/Equisetum sp.-Arctostaphylos spp. (WS5).***—Total overstory cover of this community averages 81 percent and ranges from 47 to 129 percent. The dominant overstory species is white spruce; balsam poplar and aspen are infrequent associates. The tall shrub layer is dominated by willow which has an average cover of 34 percent. The most abundant low shrub, buffaloberry, has a cover value of 19 percent and is often associated with rose. The herbaceous layer is fairly well developed with many species. The most abundant are *Equisetum* sp., bearberry, and red-fruit bearberry with an average cover value of 18, 18, and 14 percent, respectively. The moss and lichen layer appears to be well developed. Mosses average 50 percent of the cover and can be as much as 100 percent. Further study is needed to determine if this group of plots belongs to previously described communities.

This community occupies sites at low elevation (147 m) in the southwest portion of the unit. It occurs mainly on flood plains or sites associated with smaller stream drainages, on poorly drained to well-drained Typic Cryofluvents and Typic Cryochrepts. Depth to permafrost averages 67 cm, but rooting depth only 23 cm. Mineral soil pH averages 7.2. The average stand age is 85 years.

The number of stems greater than 2.5 cm in d.b.h. averages 2,605/ha. The average diameter is 10.1 cm, and Reineke's (1933) SDI is 608. Stand biomass averages 7.2 kg/m<sup>2</sup>; CAI, 765 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 39.0 g/yr.

The community described here was not reported by Viereck and Dyrness (1980).

***Picea glauca/Shepherdia canadensis-Rosa acicularis/Arctostaphylos spp.-***

***Equisetum* (WSY5).**—This community has an overstory cover of 16 percent, composed primarily of white spruce. Aspen, balsam poplar, and black spruce are common to rare associates. This young community is almost identical to WS5 in vegetative composition and is named for the same species. There are only minor differences in the vegetative descriptions for the two sites, so the reader is referred to the description of WS5.

The young version of this community occurs throughout the Yukon Flats section at an average elevation of 175 m. It is also found at lower elevations in the Porcupine Plateau section. Like the mature community, these stands occur mainly on Typic Cryochrepts and Typic Cryofluvents with an average depth to permafrost of 93 cm. The rooting depth averages 28 cm, and the humus layer is about 6 cm thick. The mineral soil is nearly neutral, with an average pH of 6.9. Stand age averages 22 years.

The average number of stems greater than 2.5 cm is 728/ha, and d.b.h. averages 4.9 cm. Stand biomass averages 0.5 kg/m<sup>2</sup>; CAI, 30 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 15.2 g/yr. An average of 5,711 seedlings/ha were recorded.

***Picea glauca/Alnus crispa/Rosa acicularis/Arctostaphylos rubra* (WS6).**—Overstory cover for this community averages 99 percent and is composed mainly of white spruce with birch and black spruce as occasional associates. The predominant tall shrub is American green alder with an average cover of 14 percent. Willow is a common associate. The low shrub layer is dominated by rose with an average cover value of 4 percent. The herbaceous layer is dominated by red-fruit bearberry and mountain cranberry with average cover values of 9 and 26 percent. The moss and lichen layer is poorly developed and appears to have no dominant species.

This community occurs on hilly and rolling uplands throughout the Yukon Flats section. It occurs on Typic Cryofluvents or Histic Pergelic Cryaquepts. Elevation averages 215 m. The average depth to permafrost is 59 cm. The humus layer averages 10 cm, and the mineral soil is somewhat acid with an average pH of 6.3. The average stand age is 90 years.

The average number of stems is 3,395/ha. Diameter at breast height averages 9.1 cm. Reineke's (1933) SDI is 671. Stand biomass averages 7.3 kg/m<sup>2</sup>; CAI, 751 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 36.3 g/yr.

This community was not described by Viereck and Dyrness (1980). The community is similar to WS2 and probably represents an upland version, with the reduced active layer reflected in the vegetative composition and overstory productivity.

***Picea glauca/Rosa acicularis-Shepherdia canadensis/Arctostaphylos rubra-Linnaea borealis* (WS7).**—The overstory cover of this community averages 86 percent and is predominantly composed of white spruce. Aspen and balsam poplar are rare associates. The tall shrub layer is composed of several species of willow. The low shrub layer is dominated by rose and buffaloberry with average cover values of 21 and 26 percent. The dominant species in the low shrub layer are red-fruit bearberry and twinflower with average cover values of 23 and 20 percent. Common associates include *Equisetum* spp., bluebells, and wintergreen. The major species in the moss and lichen layer are *Parmelia* spp., *Hylocomium splendens*, and *Peltigera* sp. with average cover values of 9, 39, and 12 percent.

This community is found throughout the Yukon Flats section, predominantly on moderately well-drained stream terraces at an average elevation of 194 m. It occurs on Typic Cryofluvents of Typic Cryochrepts with an average depth to permafrost of 80 cm. The average thickness of the humus layer is 11 cm, and the mineral soil is neutral with an average pH of 7.0. Stand age averages 110 years.

The number of stems with an average diameter at breast height of 11 cm is 2,182/ha. Reineke's (1933) SDI is 584. Biomass averages 6.9 kg/m<sup>2</sup>, and the average CAI is 651 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 34.4 g/yr and ranges from 24.9 to 43.9.

This community appears to be similar to the *Picea glauca/Linnaea borealis-Equisetum sylvaticum* community described by Foote (see footnote 1, p. 3).

## Open Black Spruce Forests

***Picea mariana/Arctostaphylos rubra-Empetrum nigrum/Cladonia* spp. (BS10).**—Overstory cover for this community averages 59 percent and ranges from 8 to 134 percent. The major overstory species is black spruce with a rare paper birch, aspen, or white spruce. Tree production is almost exclusively black spruce. The tall shrub layer is poorly developed and may contain an occasional willow, alder, or birch. The low shrub layer is moderately developed, predominantly with rose. Rose has an average cover of 6 percent. The herbaceous layer is dominated by red-fruit bearberry and crowberry with an average cover of 16 percent each. The moss and lichen layer is dominated by *Cladonia* spp. and *Hylocomium splendens*, with average cover values of 18 and 22 percent.

This community is found throughout the inventory unit, on well-drained to poorly drained Histic Pergelic Cryaquepts on level uplands and rolling to hilly plains, and in swamps and marshes. Elevation averages 307 m and ranges from 204 to 594 m. The average rooting depth is 22 cm, and depth to permafrost averages 40 cm. The organic layer is 8 cm thick. The mineral soil is slightly acid with an average pH of 6.6. Average stand age is 100 years.

The average number of stems greater than 2.5 cm in d.b.h. is 3,900/ha. Diameter at breast height averages 5.6 cm, and Reineke's (1933) SDI is 353. Stand biomass and CAI average 2.6 kg/m<sup>2</sup> and 49 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 5.7 g/yr.

This community was not defined by Viereck and Dyrness (1980). It may represent three or four communities that could not be adequately separated with the current data. This community is similar to both the *Picea mariana/Vaccinium*/feathermoss community described by Drury (1956), Lutz (1956), and Viereck (1975) and the *Picea mariana/Rosa acicularis/Peltigera* community described by La Roi (1967) and Foote (see footnote 1, p. 3).

**Picea mariana/Betula nana-Potentilla fruticosa/Carex spp. (BS11).**—Overstory cover for this community averages 43 percent and ranges from 2 to 88 percent. The dominant overstory species is black spruce. White spruce is an occasional associate. The dominant tree reproduction is black spruce; some white spruce and paper birch are present. The tall shrub layer is relatively undeveloped with no consistent or dominant species. The low shrub layer is fairly well developed and contains a mixture of species including dwarf arctic birch, bog blueberry, and bush cinquefoil, with average cover values of 16, 10, and 11 percent. The herbaceous layer is dominated by *Carex* spp., red-fruit bearberry, *Equisetum* sp., and *Petasites* (Mill.) sp., with average cover values of 28, 13, 5, and 5 percent. The moss and lichen layer contains a wide variety of species. The two most common are *Aulacomnium* sp. and *Hylocomium splendens*, with average cover values of 17 and 20 percent.

The number of stems greater than 2.5 cm in d.b.h. averages 1,766/ha; diameter at breast height, 6.0 cm. Reineke's (1933) SDI is 179. Stand biomass and CAI average 1.4 kg/m<sup>2</sup> and 74 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area is 10.1 g/yr.

This community occurs throughout the Porcupine Plateau section and at higher elevations in the Yukon Flats section. The average elevation is 433 m; the range, from 268 to 640 m. The community is predominantly found on poorly drained to somewhat poorly drained Histic Pergelic Cryaquepts. It has also been reported on very poorly drained and excessively drained sites. Depth to permafrost averages 30 cm, and the organic layer is 9 cm thick. The average mineral soil pH is 6.7, but neutral to alkaline soils can be found. The average age of the overstory is 109 years.

This community was not described by Viereck and Dyrness (1980).

**Picea mariana/Betula nana/Carex spp. (BSY11).**—The overstory cover for this community is 2 percent. The major tree reproduction is black spruce; white spruce is a common associate. The tall shrub layer can include several species, but none are dominant or consistent. The low shrub layer is dominated by dwarf arctic birch with an average cover value of 50 percent. The moss and lichen layer is dominated by *Aulacomnium* sp., *Peltigera aphthosa* (L.) Willd., and *Cladonia* spp. This community should develop into a BS11.

This community occurs throughout the Porcupine Plateau at an average elevation of 360 m, mainly on somewhat poorly drained Histic Pergelic Cryaquepts with an average depth to permafrost of 46 cm. Thickness of the humus layer averages 7 cm, and the mineral soil pH is 5.7. The average stand age is 26 years.

The number of stems larger than 2.5 cm in d.b.h. averages 145/ha. Average d.b.h. is 3.7 cm, and Reineke's (1933) SDI is 7. Stand biomass and CAI average 0.1 kg/m<sup>2</sup> and 1 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 7.0 g/yr.

***Picea mariana/Alnus crispa/Betula nana/Vaccinium spp./Cladonia spp. (BS12).***—

Overstory cover of this community averages 37 percent. Black spruce is the dominant overstory species, and paper birch and white spruce are occasional associates. The tall shrub layer is dominated by American green alder with an average cover of 39 percent. The low shrub layer is dominated by rose and dwarf arctic birch with average cover values of 17 and 12 percent. The herbaceous layer is dominated by mountain cranberry and *Equisetum* spp. with average covers of 23 and 12 percent. The moss and lichen layer is predominantly composed of *Cladonia* sp. with an average cover of 13 percent. *Peltigera* spp. and *Cetraria* spp. are common associates.

This community occurs at relatively high elevations on level to undulating uplands in the western portion of the Porcupine Plateau section. Elevation averages 381 m. The community occurs mainly on moderately well-drained to well-drained Histic Pergelic Cryaquepts. The average depth to permafrost is 56 cm. The organic matter is 8 cm deep, and the average mineral soil pH is 6.3. Average stand age is 68 years.

The number of stems with an average d.b.h. of 6.2 cm averages 1,807/ha. Reineke's (1933) SDI is 193. Stand biomass and CAI average 1.4 kg/m<sup>2</sup> and 26 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 5.9 g/yr.

This community was not described by Viereck and Dyrness (1980).

***Picea mariana/Vaccinium uliginosum/Empetrum nigrum/Lichen (BS13).***—Overstory cover averages 27 percent and ranges from 2 to 77 percent. The major overstory species is black spruce. Tree reproduction was found on all plots and consisted predominantly of black spruce with some white spruce. The tall shrub layer is moderately well developed and dominated by willow with alder as an associate. The low shrub layer is mainly composed of Labrador-tea and bog blueberry with cover values of 19 and 24 percent. The herbaceous layer is dominated by *Carex* spp., crowberry, mountain cranberry, and red-fruit bearberry with average covers of 24, 20, 18, and 14 percent. The moss and lichen layer is dominated by species of both *Cladonia* and *Peltigera* with the moss *Hylocomium splendens*.

This community is found predominantly north of the Porcupine River in the Porcupine Plateau section. It occurs mainly on somewhat poorly drained to poorly drained Histic Pergelic Cryaquepts. Elevation averages 417 m. The average depth to permafrost is 27 cm, and the organic layer is 6 cm thick. The mineral soil is slightly acid, with an average pH of 6.7. Average overstory age is 72 years.

The average number of stems greater than 2.5 cm in d.b.h. is 1,197/ha. Diameter at breast height averages 5.4 cm, and Reineke's (1933) SDI is 102. Stand biomass and CAI average 0.9 kg/m<sup>2</sup> and 34 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 9.1 g/yr.

This community was not described by Viereck and Dyrness (1980). It may represent both an open phase and a woodland phase with the same species composition.

***Picea mariana/Vaccinium uliginosum/Arctostaphylos rubra/Dicranum* sp.**

(BSY13).—Overstory cover for this community type is 8 percent, primarily black spruce. The major tree reproduction is black spruce; white spruce is a common associate. The tall shrub layer is poorly developed but may contain willow, alder, or birch. The low shrub layer is dominated by bog blueberry with an average cover value of 23 percent. The major species in the herbaceous layer are red-fruit bearberry or crowberry, with average cover values of 14 and 13 percent. The moss and lichen layer is dominated by *Dicranum* sp. and *Cladonia* spp., with average cover values of 19 and 6 percent. This community should develop into a BS13 type at maturity.

This community was found north of the Black River in the Porcupine Plateau section. It occurs at an average elevation of 372 m. The predominant soils are somewhat poorly drained Histic Pergelic Cryaquepts. The average thickness of the humus layer is 8 cm, and the mineral soil is slightly acid with an average pH of 6.7. The average stand age is 23 years.

The average number of stems greater than 2.5 cm in d.b.h. is 494/ha. The d.b.h. averages 2.8 cm. Stand biomass and CAI average 0.2 kg/m<sup>2</sup> and 6 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 4.3 g/yr.

***Picea mariana/Salix/Potentilla fruticosa/Arctostaphylos rubra/Peltigera* spp.**

(BSY14).—Overstory cover for this association is 3 percent. The major tree reproduction is black spruce. Paper birch is a common associate. The tall shrub layer is dominated by several species of willow. The low shrub layer is dominated by bush cinquefoil and rose, with average cover values of 20 and 19 percent. The dominant species in the herbaceous layer are red-fruit bearberry and fireweed, with average cover values of 18 percent each. The moss and lichen layer is dominated by species of *Peltigera*.

This community was reported south of the Porcupine River in the Porcupine Plateau section of the unit. Elevation averages 308 m. The community is found on moderately well-drained Histic Pergelic Cryaquepts. The average depth to permafrost is 63 cm. The organic layer averages 10 cm in thickness; the mineral soil is basic, with an average pH of 7.3. Average stand age is 22 years.

The average number of stems greater than 2.5 cm in d.b.h. is 272/ha, and the average d.b.h. is 3.7 cm. Reineke's (1933) SDI is 20. Stand biomass and CAI average 0.1 kg/m<sup>2</sup> and 5 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area is 7.2 g/yr.

## **Open White Spruce-Black Spruce Forests**

***Picea glauca-Picea mariana/Vaccinium uliginosum/Arctostaphylos rubra/Dicranum sp. (WSBS10).***—Overstory cover averages 31 percent and is dominated by white spruce and black spruce. Tree reproduction is predominantly white spruce with some black spruce and paper birch. The tall shrub layer is poorly developed and might contain willow, birch, or alder. The low shrub layer is dominated by bog blueberry and bush cinquefoil with average cover of 28 and 11 percent. The herbaceous layer is dominated by red-fruit bearberry, mountain cranberry, and crowberry with cover values of 17, 18, and 18 percent. The moss and lichen layer is dominated by *Hylocomium splendens* and *Dicranum* sp. with cover values of 21 and 23 percent.

This community is found in the Porcupine Plateau section on rolling and hilly uplands at an average elevation of 500 m. It occurs mainly on somewhat poorly drained to somewhat excessively drained Histic Pergelic Cryaquepts. Depth to permafrost averages 42 cm. The organic layer is 8 cm thick. The mineral soil is neutral with an average pH of 7.0. Average stand age is 147 years.

The average number of stems greater than 2.5 cm in d.b.h. is 1,688/ha. Diameter at breast height averages 5.6 cm. Reineke's (1933) SDI is 153. Stand biomass and CAI average 1.2 kg/m<sup>2</sup> and 58 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 12.3 g/yr.

This community was not described by Viereck and Dyrness (1980).

***Picea mariana-Picea glauca/Betula nana/Arctostaphylos rubra-Vaccinium uliginosum (WSBSY10).***—The current overstory cover for this community is 2 percent. The major tree reproduction is black spruce; white spruce is a common associate. The tall shrub layer is only moderately developed and shows no dominant species. The low shrub layer is dominated by dwarf arctic birch with an average cover value of 24 percent. Bush cinquefoil is a common associate. The herbaceous layer is dominated by red-fruit bearberry and bog blueberry with average cover values of 15 and 32 percent. The dominant species in the moss and lichen layer are grasses, sedges, and *Hylocomium splendens*. This community should eventually mature into a WSBS10 type.

This community was found south of the Porcupine River in both sections of the unit. The average stand elevation is 275 m. The community occurs mainly on Histic Pergelic Cryaquepts with an average depth to permafrost of 77 cm. The humus layer averages 9 cm in thickness. The mineral soil is acid, with a pH of 6.2. The average stand age is 15 years.

***Picea mariana*-*Picea glauca*/*Ledum palustre*/*Petasites* spp./*Dicranum* sp.**

**(WSBS11).**—Overstory cover of this community averages 35 percent. The overstory is composed entirely of black spruce and white spruce. Tree reproduction is composed of black and white spruce with an occasional birch. The tall shrub layer contains grayleaf willow, littletree willow, and American green alder. The low shrub layer is dominated by Labrador-tea with a cover of 21 percent. Commonly associated species are resin birch (*Betula glandulosa* Michx.) and rose. The herbaceous layer is dominated by mountain cranberry, sweet coltsfoot (*Petasites frigidus* (L.) Franch.), and red-fruit bearberry with average cover values of 15, 4, and 26 percent. Common associates are crowberry and wintergreen. The moss and lichen layer is composed of a mixture of species; the dominant ones are *Dicranum* sp. (22 percent cover) and *Hylocomium splendens* (23 percent cover).

This community is found predominantly in the Porcupine Plateau. The average elevation is 361 m. It is found on somewhat poorly drained to very poorly drained Pergelic Cryaquepts and Pergelic Cryochrepts with an average slope of 9 percent. Depth to permafrost averages 58 cm, and the organic layer is 16 cm deep. The mineral soil pH is 6.3. Average stand age is 63 years.

The average number of stems greater than 2.5 cm in d.b.h. is 2,464/ha. The average d.b.h. is 5.1 cm, and Reineke's (1933) SDI is 192. Stand biomass and CAI average 1.2 kg/m<sup>2</sup> and 30 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area is 7.0 g/yr.

This community was briefly described by Viereck (1979) as the black spruce-white spruce/resin birch/feathermoss community. It may also represent a northern or higher elevation phase of the WSBS10 community.

***Picea mariana*-*Picea glauca*/*Shepherdia canadensis*/*Epilobium* spp./*Peltigera* spp.**  
**(WSBSY12).**—The current overstory cover for this community type is 3 percent. The tree reproduction is composed of white and black spruce and trembling aspen. Balsam poplar and white birch are common associates. The tall shrub layer is composed of several species of willow; the most common is Scouler willow. The low shrub layer is dominated by buffaloberry and rose with average cover values of 18 and 6 percent. The herbaceous layer is dominated by *Epilobium* spp. with an average cover value of 7 percent. The moss and lichen layer is dominated by *Peltigera* spp. and litter with average cover values of 19 and 70 percent.

This community occurs in the south-central portion of the unit on rolling and hilly uplands predominantly in the Porcupine Plateau at an average elevation of 217 m. It occurs mainly on well-drained Histic Pergelic Cryaquepts with a depth to permafrost of 106 cm. Average rooting depth is 32 cm. The humus layer is 3 cm thick, and the average mineral soil pH is 7.0. The average stand age is 13 years.

The average number of stems greater than 2.5 cm in d.b.h. is 370/ha, and the average d.b.h. is 3.4 cm. Reineke's (1933) SDI is 15. Stand biomass and CAI average 0.2 kg/m<sup>2</sup> and 4 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 6.2 g/yr.

## **Open White Spruce Forests**

***Picea glauca/Salix bebbiana/Rosa acicularis/Equisetum sp.-Epilobium sp./Lichen (WS10).***—Total overstory cover averages 54 percent. The overstory is dominated by white spruce; aspen and birch are present only rarely. The majority of the tree reproduction is white spruce. The tall shrub layer is dominated by several species of willow. The most prominent is bebb willow with an average cover of 22 percent. The low shrub layer is dominated by rose with an average cover of 12 percent. The herbaceous layer is well developed with an average cover of 106 percent. Major species in the herbaceous layer are twinflower, *Equisetum* sp., and fireweed, with average covers of 11, 17, and 12 percent. Commonly associated species are mountain cranberry, red-fruit bearberry, and geocaulon. The moss and lichen layer is dominated by lichen. The two dominant genera are *Parmelia* and *Peltigera* with average covers of 4 and 10 percent. Other commonly associated species are *Cetraria* spp., *Cladonia* spp., and *Hylocomium splendens*.

This community is found predominantly north of the Black River in the Yukon Flats section, mainly on somewhat poorly drained to well-drained Histic Pergelic Cryaquepts and occasionally on Typic Cryochrepts and Typic Cryofluvents. Depth to permafrost averages 92 cm, and rooting depth is about 28 cm. Mineral soil pH is basic, averaging 7.8. Stand age averages 111 years and ranges from 45 to 250 years.

The number of stems greater than 2.5 cm in d.b.h. averages 1,960/ha and ranges from 537 to 4,668. Average d.b.h. is 10.9 cm, and the average value for Reineke's (1933) SDI is 517. Biomass and CAI average 4.5 kg/m<sup>2</sup> and 468 g/m<sup>2</sup> per year. The average CAI per square centimeter of basal area is 38.7 g/yr.

This community has not been described in current classifications of Alaska vegetation. The community does have a closed forest associate (WS1). The primary differences between the WS10 and the WS1 communities are: (1) WS1 has a closed canopy, and (2) the average cover of rose is much higher in WS10 because of the open canopy. There are also differences in the herbaceous layer that are undoubtedly a result of the difference in canopy closure.

***Picea glauca/Salix/Shepherdia canadensis/Vaccinium vitis-idaea (WS11).***—Over-story cover for this community averages 51 percent; it is predominantly composed of white spruce with aspen and black spruce as rare components. The tall shrub layer is composed of various species of willow. The low shrub layer is predominantly buffaloberry and rose, each with an average cover value of 19 percent. The herbaceous layer is dominated by mountain cranberry and red-fruit bearberry with average cover values of 25 and 22 percent. Common associates include equisetum, wintergreen, and twinflower. The moss and lichen layer is dominated by *Peltigera* spp. and *Cetraria* spp., with average cover values of 20 and 8 percent. Common associates include *Hylocomium splendens* and *Cladonia* spp.

This community occurs throughout the Yukon Flats section and on stream terraces in the Porcupine Plateau at an average elevation of 220 m. It occurs mainly on moderately well-drained Typic Cryochrepts and Histic Pergelic Cryaquepts with an average depth to permafrost of 73 cm. The average rooting depth is 29 cm. The humus layer averages 7 cm in thickness, and the mineral soil is somewhat acid, with an average pH of 6.5. The average stand age is 74 years.

The average number of trees greater than 2.5 cm in d.b.h. is 3,442/ha, with an average d.b.h. of 7.0 cm. Reineke's (1933) SDI is 446. Stand biomass averages 3.8 kg/m<sup>2</sup>, and CAI averages 257 g/m<sup>2</sup> per year. The average CAI per square centimeter of basal area is 20.3 g/yr.

This community was not described by Viereck and Dyrness (1980).

***Picea glauca/Salix/Ledum palustre/Vaccinium vitis-idaea (WSY11)***.—This community has an overstory cover of 11 percent, comprised primarily of white spruce. The major tree reproduction is white spruce with birch and aspen as associates. This community is expected to mature into a WS11 type. The major tall shrubs are bebb willow, littletree willow, and American green alder. The primary low shrub is Labrador-tea with an average cover of 10 percent. The primary species in the herbaceous layer are mountain cranberry and bluejoint (*Calamagrostis canadensis* (Michx.) Beauv.) with average cover values of 18 and 29 percent.

This type occurs throughout the unit at an average elevation of 268 m, on very poorly drained to well-drained Histic Pergelic Cryaquepts with an average depth to permafrost of 79 cm. The humus layer averages 5 cm in thickness, and the average mineral soil pH is 6.1. Stand age averages 15 years.

The average number of stems with an average d.b.h. of 2.5 cm is 241/ha. Reineke's (1933) SDI is 6. Overstory biomass averages 0.1 kg/m<sup>2</sup>, and the CAI averages 4 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 11.6 g/yr.

#### Woodland Black Spruce Forests

***Picea mariana/Betula nana/Eriophorum spp./Sphagnum spp. (BS20)***.—The total overstory cover for this community is 9 percent. It is dominated by black spruce. Tree reproduction is a mixture of black spruce and scattered paper birch. The tall shrub layer, if present, is composed of alder or willow. The low shrub layer is composed of dwarf arctic birch and Labrador-tea with average cover values of 40 and 13 percent. The herbaceous layer is composed mostly of mountain cranberry, *Carex* spp., and *Eriophorum* spp. with average cover values of 11, 4, and 4 percent. The moss and lichen layer is dominated by *Sphagnum* spp. with an average cover of 44 percent.

This community can occur in either the Yukon Flats or the Porcupine Plateau section of the unit. It occurs in swamps and marshes and represents a classic tussock community. Depth to permafrost averages 46 cm and the organic depth 33 cm. Average stand age is 50 years. The community occurs on Histic Pergelic Cryaquepts.

The average number of stems greater than 2.5 cm is 445/ha, and average d.b.h. is 4.2 cm. Reineke's (1933) SDI is 25. Stand biomass and CAI average 0.2 kg/m<sup>2</sup> and 3 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 5.0 g/yr.

This community is similar to the *Picea mariana/Eriophorum* sp. woodland of Dyrness and Grigal (1979), but the community described here contains a much larger cover of arctic dwarf birch and probably represents a northern phase of the described community.

**Picea mariana/Salix/Hylocomium splendens-Cladonia rangiferina (BS21).**—The total overstory cover for the community is 16 percent and is composed of black spruce with some paper birch or white spruce. Tree reproduction is predominantly black spruce, but white spruce can be found. The tall shrub layer is dominated by willow species with alder as a common associate. The low shrub layer does not appear to be well developed but could contain Labrador-tea, dwarf arctic birch, or rose. The herbaceous layer is dominated by crowberry and bearberry, both with average cover values of 24 percent. The major species in the moss and lichen layer are *Hylocomium splendens* and *Cladonia rangiferina* with average cover values of 46 and 33 percent.

This community type occurs throughout the Porcupine Plateau section, predominantly on rolling and hilly plains. The average elevation is 445 m. The community occurs on somewhat poorly drained Histic Pergelic Cryaquepts with an average depth to permafrost of 20 cm. The humus layer is 5 cm thick, and mineral soil pH averages 6.4. Average stand age is 86 years.

The average number of stems greater than 2.5 cm is 2,135/ha. Average d.b.h. is 6.4, and Reineke's (1933) SDI is 240. Stand biomass and CAI average 1.8 kg/m<sup>2</sup> and 34 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 5.8 g/yr.

This community was described as the *Picea mariana/Sphagnum-Cladonia* community of Viereck (1975, 1979).

#### Closed Aspen Forests

**Populus tremuloides/Salix spp./Drepanocladus sp. (A1).**—Total overstory cover averages 97 percent for this community type. White spruce appears as reproduction in all plots. The tall shrub layer is dominated by several species of willow. The low shrub layer is predominantly rose and buffaloberry with average cover values of 14 and 21 percent. The herbaceous layer shows no distinct dominant species. The most common species in the moss layer is *Drepanocladus* sp.

These hardwood forests are found throughout the inventory unit, mainly on well-drained Histic Pergelic Cryaquepts. Permafrost is relatively deep, averaging 109 cm. Average rooting depth is 58 cm. Humus thickness averages 4 cm. Mineral soil pH is slightly acid, averaging 6.9 and ranging from 6.1 to 8.0. The average age of these stands is 62 years, definitely considered mature for hardwood stands in the inventory unit (Yarie 1981).

The number of trees greater than 2.5 cm in d.b.h. averages 4,137/ha and ranges from 1,741 to 8,818. Reineke's (1933) SDI averages 549. The total overstory biomass averages 4.2 kg/m<sup>2</sup> and ranges from 0.6 to 8.1 kg/m<sup>2</sup>. The CAI averages 133 g/m<sup>2</sup> per year; again, there was a wide range in values, from 17 to 269 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 10.2 g/yr.

This community appears to be similar to the *Populus tremuloides/Salix spp./Arctostaphylos uva-ursi* community described by Viereck (1975).

## Closed Balsam Poplar Forests

***Populus balsamifera/Alnus-Salix/Rosa acicularis/Equisetum* (BP1).**—Total overstory cover for this community averages 102 percent and is totally dominated by balsam poplar. The majority of the tree regeneration is balsam poplar. White spruce is a rare component of this community. The tall shrub layer is dominated by thin leaf alder and feltleaf willow. The low shrub layer always contains rose, with an average cover value of 21 percent. Commonly associated species include red-osier dogwood (*Cornus stolonifera* Michx.) and highbush cranberry (*Viburnum edule* (Michx.) Rat.). The herbaceous layer is dominated by *Equisetum* sp. with an average cover of 28 percent. The moss and lichen layer is poorly developed because of large quantities of litter fall from the overstory.

This community is restricted to the flood plain and stream terraces of the major rivers within the Yukon Flats section of the unit. This community probably occurs in the entire unit, but outside the Yukon Flats it is limited because of a lack of suitable flood plain habitat. The stands are always found on moderately well-drained to well-drained Typic Cryofluvents. When present, permafrost is deep, averaging over 150 cm. Thickness of the humus layer averages 5 cm, and the mineral soil is alkaline with a pH of 8.0. The average age of these stands is 65 years.

Stand density averages 1,479 stems/ha and ranges from 821 to 2,214. Reineke's (1933) SDI averages 603 and ranges from 355 to 697. Overstory biomass averages 8.1 kg/m<sup>2</sup> and ranges from 5.3 to 11.3 kg/m<sup>2</sup>. CAI averages 290 g/m<sup>2</sup> and ranges from 188 to 398 g/m<sup>2</sup>. The CAI per square centimeter of basal area averages 13.7 g/m<sup>2</sup> per year.

This community appears to be similar to the tree-line community (*Populus balsamifera/Salix-Alnus/herb*) described by Viereck (1979). The dominant herb, bluejoint, has been replaced by *Equisetum*. Bluejoint will occur in about half the stands representing this community.

***Populus balsamifera/Rosa acicularis/Equisetum* sp.-*Pyrola* spp. (BPY1).**—This community will represent a closed community at maturity. The overstory cover averages 19 percent and is dominated by balsam poplar. Tree reproduction includes white spruce and black spruce, balsam poplar, and aspen. *Pyrola* and *Equisetum*, both typical of the mature balsam poplar stands, are present in the herbaceous layer. No consistently dominant species were found in the moss and lichen layer, indicating that this single young community may become two or three different mature communities.

This young community can be found throughout the inventory unit. The average depth to permafrost is 78 cm, and the average mineral soil pH is 7.1. Both reflect the relatively young average age of 22 years.

The average number of trees greater than 2.5 cm in d.b.h. is 510/ha; 8,472 seedlings per hectare are also present. Biomass and CAI average 0.5 kg/ha and 18 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 15 g/yr.

***Populus balsamifera/Arctostaphylos uva-ursi/Peltigera spp. (BP2).***—The overstory cover of this community averages 71 percent; balsam poplar is the primary species. The tall shrub layer is dominated by willow. The low shrub layer includes rose, buffaloberry, and various willow species. The herbaceous layer is dominated by bearberry and fireweed, with average cover values of 15 and 2 percent. The moss and lichen layer is poorly developed, with an average cover of only 3.5 percent.

This community occurs in the Yukon Flats section. It appears to be an upland balsam poplar type that occurs at an average elevation of 178 m. It is found mainly on moderately well-drained Typic Cryochrepts, with an average depth to permafrost of 130 cm. Rooting depth averages 28 cm. The average stand age is 50 years.

The number of stems greater than 2.5 cm averages 4,219/ha. Average d.b.h. is 5.4 cm. Reineke's (1933) SDI averages 361. Overstory biomass averages 3.1 kg/ha, and CAI averages 113 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area is 10.3 g/yr.

This community was not described by Viereck and Dyrness (1980).

#### **Closed Aspen-Balsam Poplar Forests**

***Populus tremuloides-Populus balsamifera/Rosa acicularis (ABP1).***—Total overstory cover for this community averages 91 percent. The overstory is dominated by aspen and balsam poplar. Aspen is regenerating in 100 percent of the stands, and balsam poplar in 67 percent. The tall shrub layer is dominated by willow, with an average cover of 42 percent. The most frequent low shrub is rose, with an average cover of 10 percent. A very common associate and often dominant when it does occur is buffaloberry. It has an average cover of 33 percent. The herbaceous layer has no consistently dominant species. The most frequently occurring species in 67 percent of the stands is bluebells. The moss and lichen layer is typical of hardwood communities and contains no consistently dominant species.

The average number of stems is 6,175/ha, with an average d.b.h. of 4.6 cm. Reineke's (1933) SDI is 408. Biomass averages 2.6 kg/m<sup>2</sup> and ranges from 0.9 to 4.3 kg/m<sup>2</sup>; CAI averages 86 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 10.9 g/yr and ranges from 7.5 to 16.2.

This community is found in the Yukon Flats section on several soil associations but predominantly on Typic Cryofluvents. Depth to permafrost ranges from 56 to 106 cm and averages 74 cm. The average thickness of the humus layer is 7 cm, and the mineral soil is acid with an average pH of 6.0. Average stand age is 45 years.

This community was not described by Viereck and Dyrness (1980).

***Populus tremuloides-Populus balsamifera/Rosa acicularis* (ABPY1).**—This community has an average overstory cover of less than 1 percent because of the young age of the stands. The species of tree reproduction would put this community into Viereck and Dyrness's (1980) aspen-balsam poplar group (level 4). The tall shrub layer is made up of several species of willow, and the low shrub layer is dominated by rose (10 percent average cover). Buffaloberry is a very common associate. The predominant herbaceous species is fireweed, with average cover of 20 percent. The moss and lichen layer is dominated by Graminae.

This group was found exclusively within the Yukon Flats section of the unit, in the vicinity of Fort Yukon and slightly to the east of the village. Elevation averages 139 m. The community mainly occurs on very poorly drained to moderately well-drained Typic Cryofluvents and Typic Cryochrepts, with an average depth to permafrost of 105 cm. Thickness of the humus layer averages 3 cm, and the mineral soil is neutral—average pH, 7.1 (range 6.5 to 8.0). Average stand age is 9 years.

Because of the young average stand age, only one stand had overstory large enough to appear as biomass. Seedlings averaged 9,135/ha.

This community will mature into the ABP1 community with the possible exception of stands 47 and 634. These later stands may become A1 communities.

#### Closed Aspen-Birch Forests

***Populus tremuloides-Betula papyrifera/Rosa acicularis/Arctostaphylos uva-ursi/lichen* (ABY1).**—Overstory cover is 20 percent and is predominantly composed of aspen and white birch. Tree reproduction is predominantly black spruce, aspen, and white birch. The major species in the tall shrub layer are American green alder and several species of willow. The low shrub layer is dominated by rose and buffaloberry, with average cover values of 12 and 10 percent. The herbaceous layer is dominated by bearberry and *Equisetum* spp., with average cover values of 15 and 4 percent. Commonly associated species are fireweed, twinflower, and red-fruit bearberry. The moss and lichen layer is dominated by species of *Cladonia*, *Peltigera*, and *Cetraria*, with average cover values of 8, 10, and 2 percent.

This community is located in the south-central portion of the unit at an average elevation of 256 m. It occurs predominantly on well-drained Typic Cryochrepts or Typic Cryorthents with an average depth to permafrost of 100 cm. The average rooting depth is 31 cm. Thickness of the humus layer is 6 cm, and the mineral soil is acid with an average pH of 6.0. The average stand age is 23 years.

The average number of stems greater than 2.5 cm in d.b.h. is 1,334/ha, and average d.b.h. is 3.3 cm. Reineke's (1933) SDI is 28. Stand biomass and CAI average 0.6 kg/m<sup>2</sup> and 23 g/m<sup>2</sup> per year. The average CAI per square centimeter of basal area is 11.2 g/m<sup>2</sup> per year.

This community appears to be similar to the ABSY1 community.

## Open Aspen Forests

***Populus tremuloides/Salix spp./Arctostaphylos uva-ursi/Graminae (A10).***—Total overstory cover averages 53 percent and ranges from 21 to 64 percent. The predominant overstory species is aspen, although white spruce can occur. White spruce is rare in the tree seedling layer. The tall shrub layer is dominated by willow, with an average cover of 25 percent. The low shrub layer is dominated by rose and buffaloberry, with average cover values of 5 and 10 percent. The herbaceous layer is dominated by bearberry, with average cover of 48 percent. Common associates include bedstraw (*Galium boreale* L.) and bluebells. The moss and lichen layer is dominated by various grasses, but they average only 4 percent cover.

These hardwood forests are found throughout the Yukon Flats section of the unit at an average elevation of 187 m. The stands are found predominantly on Typic Cryofluvents which are well drained. Rooting depth averages 23 cm, and the average depth to permafrost is 74 cm. The average thickness of the organic layer is 3.0 cm, and the mineral soil is acid with an average pH of 6.1. Average stand age is 45 years.

Stem density is slightly higher on the average than in community A1—4,475 stems/ha. But the average diameter is slightly less, 4.9 cm. Reineke's (1933) SDI is 327. Overstory biomass averages 2 kg/m<sup>2</sup>; and CAI, 67 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 10.1 g/yr and ranges from 7.1 to 18.1.

This community appears to be similar to the *Populus tremuloides/Salix spp./Arctostaphylos uva-ursi* community described by Viereck (1975).

***Populus tremuloides/Salix spp./Arctostaphylos uva-ursi—Epilobium spp. (AY10).***—The overstory cover of this community is 44 percent, composed predominantly of aspen. Tree reproduction is mainly aspen, but white spruce is a common associate. For this reason it is difficult to determine into which mature community type these stands will proceed. They could develop into any one of three: A1, A10, or AWS2. The tall shrub layer is composed of several willow species. Buffaloberry and rose are the primary components of the low shrub layer, with average cover values of 22 and 8 percent. The herbaceous layer is dominated by bearberry and fireweed, with average cover values of 18 and 4 percent. Common associates include bluebells and bedstraw. The most prominent group in the moss and lichen layer is Graminae.

This community occurs predominantly in the Yukon Flats section, at an average elevation of 138 m. It is also widely scattered throughout the Porcupine Plateau at an average elevation of 526 m. It occurs mainly on moderately well-drained to well-drained Typic Cryochrepts and Typic Cryofluvents, with an average depth to permafrost of 92 cm. The average rooting depth is 27 cm, and the humus depth averages 4 cm. The mineral soil pH is 7.0. The average stand age is 29 years.

There are about 3,182 overstory trees per hectare with an average d.b.h. of 4.8 cm. Reineke's (1933) SDI averages 225. Overstory biomass and CAI average 1.5 kg/m<sup>2</sup> and 51 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 90 g/yr. The average number of seedlings is 8,336/ha.

## Closed Aspen-White Spruce Forests

***Populus tremuloides-Picea glauca/Salix/Epilobium (AWS1)***.—Overstory cover for this community averages 97 percent and is dominated by aspen and white spruce. Tree reproduction is also dominated by both species. The tall shrub layer is made up of several willow species. The low shrub layer is predominantly rose and buffaloberry, with average cover values of 6 and 29 percent. The two main distinguishing species for this community, fireweed and *Pyrola* sp., occur in the herbaceous layer, each with 4 percent cover. The understory is dominated by lichens. The major genera are *Peltigera*, *Cladonia*, and *Cetraria*.

This community occurs predominantly in the Yukon Flats section, but it was also reported in the western section of the Porcupine Plateau south of the Porcupine River. This community occurs on moderately well-drained Histic Pergelic Cryaquepts and Typic Cryochrepts, with an average depth to permafrost of 87 cm. The average rooting depth is 32 cm. The humus layer is 6 cm thick, and the mineral soil is somewhat acid with an average pH of 6.3. The average stand age is 62 years.

The number of stems greater than 2.5 cm in d.b.h. averages 4,206/ha and ranges from 1,401 to 7,039. Reineke's (1933) SDI averages 731 for this community type. Average community biomass is 6.0 kg/ha. Average CAI is 258 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 14.2 g/yr.

This community appears to be similar to the *Populus tremuloides-Picea glauca/Arctostaphylos uva-ursi* community described by Lutz (1956), Buckley and Libby (1959), and Viereck (1975). It could be considered a northern phase in which the importance of bearberry will increase with community age.

***Populus tremuloides-Picea glauca/Salix/Epilobium (AWSY1)***.—The present overstory cover for this community is 74 percent, predominantly aspen and white spruce. The tree regeneration also appears to be about equally composed of aspen and white spruce. The tall shrub layer is exclusively willow. The low shrub layer is composed about equally of buffaloberry and rose. The major herbaceous species are fireweed and bluebells. Unlike the mature community type, wintergreen is present in only about 25 percent of the stands. This community type will undoubtedly develop into the AWS1 community type.

This community occurs exclusively in the Yukon Flats at an average elevation of 150 m. It predominantly occurs on moderately well-drained to well-drained Typic Cryochrepts and Typic Cryofluvents with an average depth to permafrost of 98 cm. Rooting depth averages 31 cm, and the humus layer averages 4 cm in thickness. The mineral soil is basic, with an average pH of 7.1. The average stand age is 28 years.

The average number of stems is 4,282/ha, and average d.b.h. is 4.3 cm. Reineke's (1933) SDI is 254. Overstory biomass averages 2.5 kg/m<sup>2</sup> and CAI 99 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 9.3 g/yr.

***Populus tremuloides-Picea glauca/Salix/Arctostaphylos uva-ursi (AWS2).***—Overstory cover averages 77 percent and is composed predominantly of aspen and white spruce. White spruce is the main regenerating overstory species, but aspen is a common associate. The tall shrub layer is dominated by willow. The low shrub layer is composed mainly of rose and buffaloberry, with average cover values of 5 and 12 percent. The main herbaceous species are bearberry, fireweed, and bluebells, with average cover values of 5, 2, and 2 percent. The moss and lichen layer is composed mainly of lichen; *Peltigera* and *Cladonia* are the predominant genera.

This community type is located almost exclusively in the Yukon Flats section of the unit at an average elevation of 181 m. It occurs predominantly on moderately well-drained to well-drained Typic Cryofluvents and Histic Pergelic Cryaquepts with an average depth to permafrost of 89 cm. Average rooting depth is 29 cm. Thickness of the humus layer averages 5 cm, and the mineral soil is slightly acid, with an average pH of 6.8. Average stand age is 56 years.

The number of overstory stems averages 4,086/ha; d.b.h. averages 7.1 cm. Biomass averages 4.4 kg/m<sup>2</sup> and ranges from 0.6 to 6.4 kg/m<sup>2</sup>. Average CAI is 258 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 18.3 g/m<sup>2</sup> per year. This community is slightly more productive than the AWS1 community.

This community appears to be similar to the *Populus tremuloides-Picea glauca/Arctostaphylos uva-ursi* community described by Lutz (1956), Buckley and Libby (1959) and Viereck (1975). This community and community AWS1 should possibly be considered as one group in a very dynamic succession proceeding to a number of white spruce community types.

***Populus tremuloides-Picea glauca/Salix/Arctostaphylos uva-ursi (AWSY2).***—This community has an overstory cover of 37 percent, composed mainly of aspen and white spruce. The remainder of the vegetation structure is similar to AWS2. At present, fireweed and bluebells are slightly more common than bearberry, but this is a result of the young average stand age.

This community occurs exclusively in the Yukon Flats at an average elevation of 160 m. It is found predominantly on moderately well-drained to well-drained Typic Cryochrepts and Typic Cryofluvents with an average depth to permafrost of 114 cm. The humus layer is about 3 cm thick; the mineral soil is basic, with an average pH of 7.1. The average stand age is 18 years.

The average number of stems per hectare is 2,582, and average d.b.h. is 4.4 cm.. The average number of seedlings is 8,935/ha. Total overstory biomass averages 1.3 kg/m<sup>2</sup>; CAI, 39 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 6.2 g/yr.

This community type is considered to be a temporary stage that will progress to AWS2.

## Closed Aspen-Black Spruce Forests

### ***Populus tremuloides-Picea mariana/Salix/Rosa acicularis/Equisetum* sp.**

(ABSY1).—The overstory cover of this community averages 71 percent. The overstory is mainly composed of aspen, black spruce, and birch. The tall shrub layer is dominated by grayleaf willow and American green alder. The low shrub layer is mainly composed of rose, with an average cover of 6 percent. The dominant herbaceous species are *Epilobium* spp. and *Equisetum*, with average cover values of 2 and 3 percent. Common associates include twinflower, red-fruit bearberry, mountain cranberry, and bog blueberry. The major genus found in the moss and lichen layer is *Peltigera*.

This community occurs mainly in the Porcupine Plateau section of the unit, on rolling and hilly uplands at an average elevation of 347 m. It is found mainly on well-drained to somewhat excessively drained Histic Pergelic Cryaquepts with an average depth to permafrost of 90 cm. The average rooting depth is 37 cm, and the humus thickness averages 4 cm. Average stand age is 23 years.

The number of stems greater than 2.5 cm in d.b.h. averages 5,864/ha; average d.b.h. is 5.3 cm. Overstory biomass and CAI average 2.7 kg/m<sup>2</sup> and 92 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 9.7 g/yr.

To project how these stands will develop is difficult, but at present it appears that they will eventually become BS2 community types.

***Populus tremuloides-Picea mariana/Salix/Lupinus* spp. (ABSY2).**—The overstory cover for this community type is 3 percent, composed mainly of aspen. The major species of tree reproduction are black spruce, white spruce, and aspen. The tall shrub layer is dominated by willow. The low shrub layer is dominated by bush cinquefoil and rose, with average cover values of 10 and 6 percent. The major species in the herbaceous layer is lupin with an average cover value of 19 percent. Commonly associated species are red-fruit bearberry, fireweed, and wintergreen. The major genus in the moss and lichen layer is *Peltigera*.

This community was scattered through the unit, predominantly on level and undulating uplands at an average elevation of 222 m. It was found on moderately well-drained Histic Pergelic Cryaquepts with an average slope of 8 percent. Depth to permafrost averages 83 cm, and the humus layer is 5 cm thick. The mineral soil is acid with a pH of 6.3, and the average stand age is 22 years.

The number of stems greater than 2.5 cm in d.b.h. averages 445/ha. Average d.b.h. is 3.0 cm. Reineke's (1933) SDI is 15. Stand biomass and CAI average 0.1 kg/m<sup>2</sup> and 3 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 6.6 g/yr.

This community should develop into a white spruce-black spruce forest type if the spruce can withstand the heavy competition from the willow cover.

## Closed White Spruce-Birch Forests

***Picea glauca-Betula papyrifera/Alnus-Salix/Galium boreale* (WSB1).**—The overstory cover of this community averages 59 percent, with equal amounts of white spruce and white birch in the overstory. The tall shrub layer is dominated by American green alder and various species of willow. The low shrub layer contains rose in various quantities (that is, cover ranges from 1.5 to 41.5 percent). The herbaceous layer is dominated by a relatively sparse cover of bedstraw (1 percent) and *Equisetum* spp. (average 9 percent). Several other herbaceous species were reported. The moss and lichen layer consistently contains a small cover of *Drepanocladus* sp. and *Cladonia* spp.

This community is found in the Yukon Flats section of the unit. It generally occurs on moderately well-drained Typic or Pergelic Cryochrepts. Depth to permafrost is shallow, averaging 32 cm. The organic layer is about 5.5 cm thick. The average age of these stands is 55 years.

Density of stems over 2.5 cm in d.b.h. averages 648/ha and ranges from 463 to 832. Average overstory biomass is 3.6 kg/m<sup>2</sup>. Overstory CAI ranges from 172 to 380 g/m<sup>2</sup> per year; average, 210 g/m<sup>2</sup> per year. Reineke's (1933) SDI is 276. Average CAI per square centimeter of basal area is 31.9 g/yr, reflecting the presence of white spruce.

This community was not described by Viereck and Dyrness (1980).

***Picea glauca-Betula papyrifera/Salix/Epilobium* spp. (WSBY1).**—Overstory cover for this community is 18 percent. The major species of tree reproduction are paper birch and white spruce. The tall shrub layer is dominated by grayleaf willow, with an average cover value of 21 percent. Rose, with an average cover value of 6 percent, is the dominant species in the low shrub layer. The dominant species in the herbaceous layer are fireweed, bluebells, and *Equisetum*, with average cover values of 11, 5, and 18 percent.

This community occurs throughout the unit at an average elevation of 226 m, mainly on moderately well-drained Histic Pergelic Cryaquepts or Typic Cryochrepts with an average depth to permafrost of 94 cm. The humus layer averages 6 cm in depth, and the mineral soil is acid with an average pH of 6.3. The average stand age is 13 years.

The number of stems greater than 2.5 cm averages 567/ha, and d.b.h. averages 2.7 cm. Reineke's (1933) SDI is 16. Biomass averages 1.0 kg/m<sup>2</sup>; the CAI, 27 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 17 g/yr.

## Closed Black Spruce-Birch Forests

***Picea mariana-Betula papyrifera/Arctostaphylos uva-ursi/Lichen (BSBY1).***—Overstory cover for this community averages 41 percent and is primarily composed of black spruce and white birch. The major tree reproduction is black spruce. The major species in the tall shrub layer are grayleaf willow and bebb willow. The low shrub layer is poorly developed and shows no consistent or dominant species. The herbaceous layer is dominated by bearberry and *Epilobium* spp., with average cover values of 6 and 3 percent. The moss and lichen layer is dominated by *Peltigera* spp. and *Cladonia* spp., with average cover values of 13 and 15 percent.

This community occurs throughout the southern portion of the unit in the Porcupine Plateau section. Average elevation is 397 m. The community occurs on somewhat poorly drained to somewhat excessively drained Histic Pergelic Cryaquepts. Average depth to permafrost is 58 cm. The average humus thickness is 3 cm, and the mineral soil is acid—average pH, 6.0. Average stand age is 25 years.

The number of stems greater than 2.5 cm in d.b.h. averages 1,379/ha. Average d.b.h. is 5.2 cm, and Reineke's (1933) SDI is 111. Stand biomass and CAI average 0.7 kg/m<sup>2</sup> and 22 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 10.7 g/m<sup>2</sup> per year.

***Picea mariana-Betula papyrifera/Ledum palustre/Vaccinium vitis-idaea (BSBY2).***—Overstory cover for this community type is 25 percent and is composed predominantly of black spruce and birch. Tree reproduction is dominated by black spruce with birch as a common associate. The major species in the tall shrub layer are American green alder and bebb willow. The low shrub layer is dominated by Labrador-tea and rose, with average cover values of 11 and 5 percent. The major species in the herbaceous layer is mountain cranberry, with an average cover value of 32 percent. The moss and lichen layer is dominated by *Cladonia* spp. and *Peltigera* spp., with average cover values of 15 and 8 percent.

This community predominantly occurs south of the Porcupine River in the Porcupine Plateau section of the unit on rolling and hilly uplands. Average elevation is 352 m. The community occurs on moderately well-drained Histic Pergelic Cryaquepts with an average depth to permafrost of 60 cm. The humus layer thickness averages 9 cm, and the mineral soil is slightly acid with an average pH of 6.6. The average stand age is 28 years.

The average number of stems greater than 2.5 cm in d.b.h. is 1,187/ha. Average d.b.h. is 4.5 cm, and Reineke's (1933) SDI is 76. Stand biomass and CAI average 0.5 kg/m<sup>2</sup> and 28 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area averages 13.6 g/yr.

## **Open Aspen-Black Spruce Forests**

***Populus tremuloides-Picea mariana/Vaccinium uliginosum/Polytrichum* sp. (ABSY10).**—Overstory cover for this community is 22 percent. It is thought that these stands will never represent a closed forest type. The main overstory species is aspen. Tree regeneration includes both aspen and black spruce. The dominant low shrub species are rose and bog blueberry, with average cover values of 13 and 11 percent. The herbaceous layer is composed of several species, the most prominent being bunchberry (*Cornus canadensis* L.), with an average cover value of 29 percent. Constant associates include mountain cranberry, crowberry, fireweed, and lousewort (*Pedicularis* L.). The prominent genus in the moss and lichen layer is *Polytrichum*.

This community occurs exclusively in the Porcupine Plateau at an average elevation of 719 m. The major soils are Pergelic Cryorthents and Histic Pergelic Cryaquepts. The average stand age is 25 years.

The number of stems averages 1,334/ha; d.b.h. averages 4.1 cm. Reineke's (1933) SDI averages 73. Biomass averages 0.4 kg/m<sup>2</sup>; CAI, 9.5 g/m<sup>2</sup> per year. The CAI per square centimeter of basal area is 6.2 g/yr.

These stands will probably develop into community BS12 or WSBS11.

## **Discussion—Vegetation Classification**

About 85 percent of the study area is forested. A conservative estimate of the total number of forest communities in the area is 50, if 80 percent of the communities are assumed to have been described in this paper. The portions of the area that received little attention because of random sampling of the unit were the "salt flats" in the vicinity of the village of Chalkyitsik, the mountains along the Canadian border, and all tundra or other nonforest areas.

The sampling design used for the forest survey allows the estimate of a number of statistics not usually available in standard vegetation classification work. A relatively good estimate of area occupied by each community is given in table 9. The area occupied by each community is a relatively small portion of the unit. Communities *Picea mariana/Ledum palustre/Vaccinium vitis-idaea/Cladonia* spp. (BS1 and BSY1), and the closed white spruce communities WS5 and WSY5 occupy the largest portion of the unit (5.9 percent). The smallest portion is occupied by BP2 (0.3 percent). Black spruce communities occupy the largest percentage of the unit—23.4 percent. White spruce and mixed conifer communities follow (19.9 and 15.4 percent).

Because of the relative uniformity of the distribution of communities across the unit, in some cases it is difficult to make any broad generalizations about community environments. In general, hardwood or mixed hardwood-conifer sites tend to be warmer and better drained than conifer sites, with the exception of flood plain white spruce sites. Few of the communities are site specific. The communities WS4 and BP1 are limited to flood plains of the major rivers. Although WS2 is also a flood plain community, it appears to be restricted to smaller drainages. Balsam poplar community BP2 appears to be restricted to upland sites.

**Table 9—Estimates of the area occupied by each community in the study area in the Porcupine River drainage**

Code	Area	Percent of total area
ha		
<b>Mature communities:</b>		
BS1	110 699	3.07
BS2	56 123	1.56
WSBS1	110 365	3.06
WSBS2	75 935	2.11
WSBS3	50 538	1.40
WSBS4	56 901	1.58
WS1	91 272	2.53
WS2	31 005	.86
WS3	39 853	1.11
WS4	12 644	.35
WS5	87 948	2.44
WS6	39 795	1.10
WS7	48 130	1.34
BS10	154 621	4.29
BS11	99 482	2.76
BS12	50 955	1.41
BS13	86 957	2.41
WSBS10	33 963	.94
WSBS11	84 067	2.33
WS10	60 776	1.69
WS11	69 356	1.92
BS20	19 357	.54
BS21	49 086	1.36
BP1	13 451	.37
BP2	10 478	.29
A1	22 529	.63
ABP1	13 696	.38
WSB1	8 321	.23
AWS1	33 663	.93
AWS2	60 097	.67
A10	20 834	.58
<b>Total</b>		<b>46.87</b>

**Table 9—Estimates of the area occupied by each community in the study area in the Porcupine River drainage, continued**

Code	Area	Percent of total area
ha		
<b>Young communities:</b>		
BSY1	119 661	3.32
WSBSY2	32 026	.89
WSBSY5	35 360	.98
WSY2	70 371	1.95
WSY5	123 181	3.42
BSY11	71 320	1.98
BSY13	66 189	1.84
BSY14	26 329	.73
WSBSY10	45 261	1.26
WSBSY12	32 019	.89
WSY11	43 734	1.21
BPY1	27 554	.76
AY10	102 316	2.84
ABPY1	45 310	1.26
AWSY1	42 137	1.17
AWSY2	64 951	1.80
ABSY10	14 339	.40
BSBY1	33 437	.93
BSBY2	54 945	1.52
ABY1	41 828	1.16
WSBY1	44 054	1.22
ABSY1	29 689	.82
ABSY2	45 332	1.26
<b>Total</b>	<b>1 211 342</b>	<b>33.61</b>
<b>Unclassified conifer communities</b>	<b>128 499</b>	<b>3.57</b>
<b>Unclassified deciduous communities</b>	<b>25 622</b>	<b>.71</b>
<b>Total unclassified area</b>	<b>154 121</b>	<b>4.28</b>
<b>Grand total</b>	<b>3 054 663</b>	<b>84.76</b>

The two closed black spruce communities can be separated by physiographic provenance, drainage, and soil order. The community BS1 is predominantly found in the Porcupine Plateau on poorly drained sites. Black spruce community BS2 is located in the Yukon Flats section but predominantly on moderately well-drained sites. One community that might be considered typical of poorly drained or somewhat poorly drained sites in Yukon Flats is BS10. Communities WS10 and WSBS2, also typical of the Yukon Flats section, may also be found on somewhat poorly drained sites. These latter two communities would probably be found on sites with better drainage than the BS10 sites. An extension of this drainage continuum would then lead to WS11 or WSBS3 sites; both communities are typical of the Yukon Flats section.

Two additional gradients are represented within the described communities. The first is a moisture gradient that goes from poorly drained to well-drained sites and corresponds to the community series WSBS4, WSBS1, WSBS2, and WSBS3. This series also follows an approximate gradient in elevation: WSBS4 and WSBS1 are at higher elevations than is WSBS3 (table 7). A moisture gradient is also apparent in the open black spruce communities in the Porcupine Plateau. The gradient goes from poorly drained sites occupied by BS13 communities to somewhat poorly drained and moderately well-drained sites occupied by BS11 and BS12 communities. Both open mixed-spruce communities are found at higher elevations in the Porcupine Plateau.

Delineation of typical sites for the closed white spruce communities was more difficult. A gradient, if one exists, appears to be related to height above or distance from major or minor streams and rivers. Community WS4 is a typical flood plain site type; WS2 is related but is found predominantly along smaller waterways. Communities WS1 and WS7 are both typical of stream terraces, which places them slightly higher above the river than flood plain sites. Communities WS3 and WS5 are removed from any river influence, and community WS6 is an upland community on rolling and hilly uplands.

Few of the communities showed distinct geographical limitations. Of the ones that did, WSBS1 was found only in the northwest quarter of the unit. Community WSBSY2 was clustered between Big Rat and Mink Lakes on the east and Chandalar Creek on the west (fig. 1). Mixed conifer community 4 (WSBS4) was found in a narrow band running from Coleen Mountain on the south past Rabbit Mountain to the northern border of the unit. Community WS5 was found exclusively in the southwest portion of the study area. Community BS13 was found along the northern boundary of the unit east of Vundik Lake (fig. 1).

It is impossible to describe typical sites for most of the hardwood communities because of their high dependence on disturbance. Most of these communities are probably transitional to some of the conifer communities if they can escape disturbance for a sufficient time.

One interesting feature of the vegetation in the study area is the prevalence of mixed white spruce-black spruce communities. In more southern portions of interior Alaska, these communities tend to occupy tree-line areas (Viereck 1979) or ecotones between white spruce and black spruce sites. A total of seven associations are reported, occupying a range of environments. One explanation for the frequency of these types in the study unit is that the latitude of the unit is much closer to the northern limit of black spruce than of white spruce. In this area white spruce begins to occupy black spruce sites, although white spruce appears to perform as poorly as black spruce. In fact, its general appearance is similar to black spruce. White spruce undoubtedly has a competitive advantage over black spruce in northern areas. White spruce may also grow slightly faster on these sites, but no data were collected to verify this.

## **Tree Biomass and Productivity**

A total of 54 trees were sampled (table 10) during two field seasons. Average tree data indicate that white spruce is the largest and most productive species in the unit (table 11). Although equivalent data for balsam poplar and aspen are lacking, balsam poplar may actually be more productive than white spruce (Van Cleve and others 1980), but white spruce will attain larger dimensions than balsam poplar.

The average size of sample trees was larger and the range of sizes wider than those collected by Johnson and Vogel (1966). Because of the differences in size, the proportions of foliage, branches, and stem are quite different. Johnson and Vogel (1966) report 27, 22, and 3 percent foliage for white spruce, black spruce, and birch; the proportion of foliage to total aboveground tree weight in this study was 9, 4, and 4 percent for the same species (table 11). The leaf:wood ratios were also much lower for the average tree sampled in this study compared with the Johnson and Vogel (1966) study. The data collected in this study suggest that leaf:wood ratios are very dependent on age, especially in vigorous trees. The average leaf:wood ratios reported in this study were 0.14, 0.05, and 0.05 for white spruce, black spruce, and birch (table 11). The value of 0.1 suggested by Johnson and Vogel (1966) may be too high a criterion to use as a survival limit for black spruce. A leaf:wood ratio closer to 0.01 may be more realistic; even at that value, black spruce may survive for several decades.

Because of the inventory methods, two sets of biomass and production equations (table 12) were necessary. Only diameter at breast height was available as an independent variable for trees from 2.54 to 12.69 cm in d.b.h. Both diameter and height were available for trees 12.70 cm in d.b.h. and greater. Only current annual production and total tree biomass were calculated. Both sets of equations are given for these components.

Estimated biomass and current annual production for the communities described are comparable to values reported for other interior Alaska forests (Barney and others 1978; Johnson and Vogel 1966; Troth and others 1976; Van Cleve and others 1980, 1981). A large range in values for biomass and production was found (tables 7 and 8), but this was expected because of the regional nature of the study.

The estimated aboveground tree biomass values ranged from 0.1 to 23.4 kg/m<sup>2</sup> for a woodland black spruce community (BS20) to a closed white spruce community (WS4). The reported mean annual increment (MAI) ranged from 4.0 to 195.0 g/m<sup>2</sup> per year for these same communities (table 13). The average aboveground tree MAI was almost 3.5 times higher in white spruce communities than black spruce communities; 24.3 g/m<sup>2</sup> per year compared with 86.7 g/m<sup>2</sup> per year. Hardwood and mixed communities had almost three times the MAI of black spruce communities (table 13). The hardwood communities will never attain the standing biomass values of the white spruce communities because they do not live as long, but their MAI is about 89 percent of the white spruce communities.

Table 10—Stand location and trees sampled for preparation of the biomass equations for Porcupine Plateau

Plot number	Site class	Latitude	Longitude	Elevation	Sample trees	
					Species	Number
m						
10	--	66°37'	142°52'	183	White spruce	2
12	--	66°38'	142°50'	183	Birch	1
13	6	66°48'	144°55'	152	Balsam poplar	2
14	--	66°48'	144°56'	152	White spruce	1
15	6	66°29'	145°11'	130	White spruce	5
16	6	66°31'	145°11'	130	Balsam poplar	2
17	7	67°25'	141°37'	305	White spruce	6
19	--	67°25'	141°37'	335	White spruce	3
21	9	66°47'	141°15'	709	White spruce	2
21	9	66°47'	141°15'	709	Black spruce	1
23	9	66°46'	141°16'	686	White spruce	6
24	6	66°14'	142° 8'	253	White spruce	6
27	6	66° 5'	142°18'	221	White spruce	2
28	6	65°20'	143°50'	457	Birch	6
29	9	65°26'	144° 3'	244	Black spruce	6

**Table 11—Average biomass data summary by species in Porcupine Plateau**

Item	White spruce				Black spruce				Birch			
	$\bar{x}$	Min.	Max.	S.E.	$\bar{x}$	Min.	Max.	S.E.	$\bar{x}$	Min.	Max.	S.E.
D.b.h. (cm)	20.6	3.85	49.96	2.36	7.8	2.50	12.75	1.43	10.1	4.30	14.8	1.64
Height (m)	14.36	3.00	30.50	1.43	7.17	2.74	10.17	1.09	13.32	10.7	15.15	.72
Age (yr)	68.1	50.00	122.00	6.19	103.00	11.00	121.00	15.37	58.8	52.0	68.0	2.63
Component weight (kg):												
Foliage	21.25	.35	98.74	5.99	.62	.11	1.30	.16	1.56	.16	3.85	.55
Current growth	1.77	.06	9.22	0.51	.75	.02	.17	.02				
Branches	33.55	.32	207.77	8.34	.89	.10	2.39	.26	6.99	.42	20.25	2.79
Live crown	60.61	.73	321.30	13.85	3.16	.23	11.88	1.31	8.77	.57	24.10	3.30
Dead branches	10.02	.01	142.44	4.20	1.31	.09	4.40	.48	1.02	.09	3.48	.46
Cones	.75	0	10.13	.39	.04	0	.10	11.54				
Total Crown	70.63	.87	340.05	15.03	4.47	.32	12.36	1.37	9.79	.66	25.76	3.61
Stemwood minus 5-yr wood increment	130.03	.48	597.86	32.57	10.12	.57	21.96	4.63	25.57	2.50	48.28	7.11
Bark	20.84	.32	102.98	4.66	2.07	.20	4.23	.57	4.46	.58	8.53	1.24
5-yr wood increment	8.45	.24	38.65	2.36	.41	.03	1.03	.15	3.43	.51	7.31	1.13
Total stem	156.78	1.12	738.11	37.92	12.51	.80	27.11	3.72	32.97	3.59	64.12	9.17
Total tree	227.71	2.15	1078.16	51.40	16.98	1.12	36.60	4.93	41.80	4.56	89.88	12.50

$\bar{x}$  = mean; S.E. = standard error.

**Table 12—Biomass and production equations derived from data collected in the Porcupine River drainage study unit<sup>1/</sup>**

Species and component	Regression coefficients							
	a	b	c	d	e	r <sup>2</sup>	Sy.x	N
<b>White spruce:</b>								
Total stem minus bark	-3256.5	863.97			8.210	0.99	2359	25
Bark	-31.929		20.836	.518	.98	756	25	
Dead branches	12140.1	-3503.1	252.0	-6.096	.52	6272	23	
Branchwood and bark	955.3			2.953	.78	6277	25	
Foliage	-2651.7		568.74	35.46	.86	4735	23	
Total tree	-1544.18			209.11	7.592	.96	13082	23
	15017.0	-4579.0		503.57		.96	15340	23
Last 5-yr stemwood increment	-2139.64		549.68	10.394	.75	1857	23	
	160.66		17.593		.68	2220	23	
Current growth	-484.277	123.06			.44	744	23	
		39.342		2.079		.48	769	23
Total current annual production	-1887.8	499.15		-18.072	.511	.75	824	23
<b>Black spruce:</b>								
Total stem minus bark	-25.574		68.532	7.316	.99	161	6	
Bark	-47.479		34.974	-.814	.99	287	6	
Dead branches	-64.643		24.312		.91	312	6	
Branchwood and bark	448.84	455.15	-517.42		.90	108	6	
Total tree	1878.0	716.37	-1390.7	222.47		.99	184.8	6
	-25.506			202.36		.99	444.6	6
Last 5-year increment	33.825		6.048		.94	60.1	6	
	16.943		6.232		.94	50.5	6	
Current growth	3.906	5.162		.581		.99	5.3	6
	-5.0257	7.977		.405		.98	4.9	6
Total current annual production	23.39		2.157			.98	12.8	6
<b>Birch:</b>								
Total stem minus bark	-1343.8		248.39		.99	1072	5	
Bark	7240.7		48.69		.99	260	5	
Dead branches	-195.18			.828	.84	455	5	
Branchwood and bark	-1908.4		79.30		.87	2691	5	
Foliage	781.61	-283.84	31.52		.99	289	5	
		-87.90	21.38		.97	268	5	
Total tree	-3813.0		390.9		.99	3798	5	
		-1047.1	447.83		.99	3540	5	
Last 5-yr stemwood increment	6580.8		-631.95	41.733		.99	204	5
				29.827		.99	327	5
Total current annual production	-297.08			22.395		.97	336	5

1/ The model is  $y = a + bx + cx_1 + dx_2 + ex_3$ ; where,  $y$  is component oven dry weight (g),  $x$  is d.b.h. (cm),  $x_1$  is height (m),  $x_2$  is (d.b.h.)<sup>2</sup>, and  $x_3$  is (x<sub>2</sub>)(height).

**Table 13—Mature community production and potential production in Porcupine River drainage, interior Alaska**

Community	Current MAI per year	Metric SDI 1/ g/m <sup>2</sup>	Estimated potential production per year			
			Total tree		Wood	
			MAI	CAI	MAI	CAI
	ft <sup>3</sup> /acre		ft <sup>3</sup> /acre	g/m <sup>2</sup>	ft <sup>3</sup> /acre	g/m <sup>2</sup>
<b>Black spruce communities:</b>						
BS1	13.5	4	365	51	95	11
BS2	77.3	17	881	88	252	19
WSBS1	19.3	4	323	60	188	13
WSBS2	37.7	8	461	82	618	18
WSBS3	46.1	10	482	96	272	21
WSBS4	17.0	4	256	56	172	14
BS10	26.0	6	353	74	139	16
BS11	12.8	3	179	72	413	16
BS12	20.6	5	193	107	134	24
BS13	12.5	3	102	123	329	27
WSBS10	8.2	2	153	54	373	12
WSBS11	19.1	4	192	99	154	22
BS20	4.0	1	5	80	40	18
BS21	20.9	5	240	87	140	19
<b>White spruce communities:</b>						
WS1	110.2	24	901	12	891	27
WS2	79.7	17	583	137	1758	30
WS3	75.3	15	594	109	603	24
WS4	195.0	42	1036	188	2130	41
WS5	84.7	18	603	139	1258	30
WS6	81.1	18	671	121	1119	26
WS7	62.7	14	534	107	1115	23
WS10	40.5	9	519	78	902	17
WS11	51.4	11	492	105	522	23
<b>Hardwood and mixed communities:</b>						
A1	67.7	17	549	123	242	30
BP1	124.6	31	603	207	480	51
BP2	52.0	15	361	313	172	19
ABP1	57.8	14	408	142	212	35
A10	44.4	11	327	136	204	33
AWS1	96.7	24	581	166	443	41
AWS2	126.8	31	441	28	585	71
WSB1	65.5	16	238	275	116	68

1/ Stand density index (Reineke 1933).

## **Application To Forest Management**

The conceptual basis that links ecosystem classification to forest management has been reviewed by Klinka and others (1979) and is only briefly described in this paper. The key to successful forest management is the ability to reliably predict forest growth and the effect of prescribed silvicultural treatments on the forest ecosystem. An ecosystem is "that part of the forest uniform over a certain area in the composition, structure and properties of its components, and in the interrelationships among them; that is, uniform in the plants, animals, and microorganisms inhabiting it, in the parent material, in its hydrological, microclimatic (atmospheric), and soil environments and the interactions among them; and in the kind of matter and energy exchange between these components and other natural phenomena in nature." This is the definition given by Sukachev and Dylis (1964) as translated by Klinka and others (1979).

Because it is impossible to quantify all components, plants and soils are most often used to describe ecosystems. In my study, the classification is based only on the plants. Plants in this case are considered to integrate and reflect all other ecosystem properties. Ideally plant, soil, and climatic variables should have been quantified for each location, but time and money precluded detailed measurements of the latter two components. The smallest unit in the classification is one that is uniform in terms of plant cover (that is, the community).

Similar ecosystems are grouped or classified so that knowledge about each ecosystem can be organized and effectively communicated. Finally, with enough information about one ecosystem, the effects of silvicultural treatments over a large area containing similar ecosystems can be predicted. The power of prediction is the important feature of ecosystem classification that can link it to effective forest management.

As an example of the application of the classification presented earlier, it is now possible to take the basic community growth data and estimate which communities have a potential for producing wood or wood fiber in sufficient quantity to sustain a commercial market. Also, an estimate can be made of the total land area within the study area that might be suitable for commercial forestry operations.

The first step in estimating potential forest productivity is to decide if each community is fully occupied by trees. Could this community support more trees without reducing growth on any one stem? Estimates of relative stand density were made by use of a metric version of Reineke's (1933) stand density index. A fully stocked stand is one that has a SDI value of 1000. Therefore, a community like WS5 which has an average SDI of 608 (table 13) is considered to be 60 percent stocked and could support 40 percent more trees with no reduction in growth on any one tree.

An estimate of potential production can be made for all communities if they are fully stocked. The average total production (MAI) for the mature communities is 47.3 g/m<sup>2</sup> (10.7 ft<sup>3</sup>/acre) per year. The estimated potential production if all stands are fully stocked is 106.3 g/m<sup>2</sup> (23.9 ft<sup>3</sup>/acre) per year (table 13). This represents a 225-percent increase in aboveground total tree and wood production.

If this potential productive capacity is to be utilized, additional criteria must also be met. These are often dictated by the commercial market and by the tools people use to extract a resource from the natural environment. For example, each community under consideration for management must be able to produce wood fiber at a given rate. In interior Alaska, this rate has traditionally been thought of as 20 ft<sup>3</sup>/acre per year (Hegg and Sieverding 1979, Hutchison 1967). In terms of current MAI, this restriction eliminates all black spruce communities, all but two of the white spruce communities, and five of the eight hardwood and mixed communities (table 13). Only 9.6 percent of the study area is currently covered by commercial forests. If the communities that might have potential to produce 20 ft<sup>3</sup>/acre or more per year are considered, all hardwood and mixed communities are included; all but one white spruce community has potential and four of the black spruce communities can support commercial forests. This group of communities covers 42.9 percent of the study area (1 546 500 ha).

In the immediate future, the communities that should be considered first for commercial operation include the flood plain or stream terrace communities of BP1, WS4, and WS1 plus the two upland aspen-white spruce communities (AWS1 and AWS2).

Other applications of the classifications to forest management can be developed. A guide to selection of tree species for regeneration and for prescribed burning could be developed. This guide could be similar to the one developed by Klinka (1977) for southwestern British Columbia. A guide to harvesting techniques or general site limitations for various harvesting techniques could be developed. Recommendations could also be made to help improve or at least maintain wildlife habitat and possible recreational opportunities. So, within the framework of an ecosystem classification, much of the knowledge needed to effectively manage forest lands can be easily organized and communicated to the manager and the public.

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## English Equivalents

<u>Metric unit</u>	<u>English equivalent</u>
1 hectare	= 2.4710 acres
1 kilogram per square meter	= 0.2048 pound per square foot
1 centimeter	= 0.3937 inch
1 cubic meter per hectare	= 14.2913 cubic feet per acre
1 gram	= 0.035 ounce
1 gram per square meter	= 0.378 ounce per square foot

## Literature Cited

- Barney, Richard J.; Van Cleve, Keith; Schlientner, Robert.** Biomass distribution and crown characteristics in two Alaskan *Picea mariana* ecosystems. *Can. J. For. Res.* 8(1): 36-41; **1978**.
- Black, C. A.**, ed. Methods of soil analysis. Madison, WI: American Society of Agronomy; **1965**. 1,572 p.
- Buckley, J. L.; Libby, W. L.** The distribution in Alaska of plant and animal life available for survival. Aeromed. Lab. Tech. Rep. 5810. Fairbanks, AK: U.S. Air Force; **1959**. 43 p.
- Daniel, T. W.; Meyn, R. L.; Moore, R. R.** Reineke's stand density index in tabular form in English and metric units with its applications. Utah Agric. Exp. Stn. Res. Rep. 37. Logan, UT: Utah State Univ.; **1979**. 9 p.
- Dick-Peddie, W. A.; Moir, W. H.** Vegetation of the Organ Mountains, New Mexico. Sci. Ser. 4. Fort Collins, CO: Colorado State Univ.; **1970**. 28 p.
- Drury, W.** Bog flats and physiographic processes in the upper Kuskokwim River region, Alaska. Contributions from the Gray Herbarium 177; **1956**. 130 p.
- Dyrness, C. T.; Grigal, D. F.** Vegetation-soil relationships along a spruce forest transect in interior Alaska. *Can. J. Bot.* 57(23): 2644-2656; **1979**.
- Farr, Wilbur A.** Growth and yield of well-stocked white spruce stands in Alaska. Res. Pap. PNW-53. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1967**. 30 p.
- Foote, J.** General patterns of forest succession in interior Alaska. In: Proceedings, 30th Alaska Scientific Conference; 1979 September 19-21; Fairbanks, AK. Fairbanks, AK: American Association for the Advancement of Science, Alaska Division, and American Chemical Society; **1979**: 20-21. Abstract.
- Franklin, Jerry F.; Dyrness, C. T.; Moir, W. H.** A reconnaissance method for forest site classification. *Shinrin Richi* 12(1): 1-14; **1970**.
- Gregory, R. A.; Haack, P. M.** Growth and yield of well-stocked aspen and birch stands in Alaska. Res. Pap. NOR-2. Juneau, AK: U.S. Department of Agriculture, Forest Service, Northern Forest Experiment Station; **1965**. 28 p.
- Hanson, H. C.** Vegetation types in northwestern Alaska and comparisons with communities in other arctic regions. *Ecology*. 34(1): 111-140; **1953**.
- Hegg, Karl M.** Forest statistics for the upper Koyukuk River, Alaska, 1971. Resour. Bull. PNW-54. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1974**. 26 p.
- Hegg, Karl M.; Sieverding, Harold.** Timber resources of the Kuskokwim flood plain and adjacent upland. Resour. Bull. PNW-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1979**. 40 p.
- Hettinger, L.; Janz, A.** Vegetation and soils of northeastern Alaska. *Arct. Gas Biol. Rep.* Ser. 21. Edmonton, AB: Northern Engineering Service, Co. Ltd.; **1974**. 206 p.

- Hill, M.** TWINSPLAN - a computer program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, NY: Ecology and Systematics, Cornell University; **1979**. 90 p.
- Hill, M.; Bunce, R. G.; Shaw, M.** Indicator species analysis, a divisive polythetic method of classification and its application to a survey of native pinewoods in Scotland. *J. Ecol.* 63(2): 597-613; **1975**.
- Hutchison, O. Keith.** Alaska's forest resource. *Resour. Bull. PNW-19*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1967**. 74 p.
- Johnson, P. L.; Vogel, T. C.** Vegetation of the Yukon Flats region, Alaska. *Res. Rep. 209*. Hanover, NH: Cold Regions Research Engineering Laboratory; **1966**. 53 p.
- Klinka, K.** Guide for the tree species selection and prescribed burning in the Vancouver forest district. Victoria, BC: Ministry of Forests; **1977**. 34 p.
- Klinka, K.; Nuszdorfer, F. C.; Skoda, L.** Biogeoclimatic units of central and southern Vancouver Island. Victoria, BC: Ministry of Forests; **1979**. 120 p.
- Krajina, V.** Die pflanzengesellschaften des Mlynica - Tales in den Vysoke Tatry (Hohe Tatras). Mit besonderer Berücksichtigung der ökologischen Verkaltinisse. *Bot. Centralbl., Beih., Abt. 2*, 50: 774-957; 51: 1-224; **1933**.
- LaRoi, George H.** Ecological studies in the boreal spruce-fir forests of the North American taiga. 1. Analysis of the vascular flora. *Ecol. Monogr.* 37(3): 229-253; **1967**.
- Lutz, H.** Ecological effects of forest fires in the interior of Alaska. *Tech. Bull. 1133*. Washington, DC: U.S. Department of Agriculture; **1956**. 121 p.
- Reineke, L. H.** Perfecting a stand-density index for even-aged forests. *J. Agric. Res.* 46: 627-638; **1933**.
- Rieger, S.; Schoephorster, D. B.; Furbush, C. F.** Exploratory soil survey of Alaska. [Place of publication unknown]: U.S. Department of Agriculture, Soil Conservation Service; **1979**. 213 p.
- Sukachev, V. N.; Dylis, H.**, eds. *O snovy lesnoi biogeocoenologii*. Moscow, USSR: Nanka; **1964**. 514 p.
- Trigg, William M.** Fire season climatic zones of mainland Alaska. *Res. Pap. PNW-126*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1971**. 12 p.
- Troth, J. L.; Deneke, F. J.; Brown, L. M.** Upland aspen/birch and black spruce stands and their litter and soil properties in interior Alaska. *For. Sci.* 22(1): 33-44; **1976**.
- Van Cleve, K.; Barney, R. J.; Schlientner, R. L.** Evidence of temperature control of production and nutrient cycling in two interior Alaskan black spruce ecosystems. *Can. J. For. Res.* 11(2):258-273; **1981**.

**Van Cleve, Keith; Dyrness, Ted; Viereck, Les.** Nutrient cycling in interior Alaska flood plains and its relationship to regeneration and subsequent forest development. In: Murray, Mayo; VanVeldhuizen, Robert M., eds. Forest regeneration at high latitudes. Gen. Tech. Rep. PNW-107. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1980**: 11-18. In cooperation with: School of Agriculture and Land Resources Management, University of Alaska.

**Van Cleve, Keith; Dyrness, Ted; Viereck, Les; Fox, John; Chapin, Terry, III; Oechel, Walt.** Taiga ecosystems in interior Alaska. *Bioscience*. 33(1): 39-43; **1983**.

**Viereck, Leslie A.** Forest ecology of the Alaska taiga. In: Proceedings, Circumpolar Conference on Northern Ecology; 1975 September 15-18; Ottawa, ON. Ottawa, ON: National Research Council; **1975**: I-1 to I-22.

**Viereck, Leslie A.** Characteristics of treeline plant communities in Alaska. *Holarctic Ecol.* 2(4): 228-238; **1979**.

**Viereck, Leslie A.; Dyrness, C. T.** A preliminary classification system for vegetation of Alaska. Gen. Tech. Rep. PNW-106. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1980**. 38 p.

**Wahrhaftig, C.** Physiographic divisions of Alaska. Geol. Surv. Prof. Pap. 482. Washington, DC; **1965**. 52 p.

**Yarie, J.** Fire cycles and life tables - a case study from interior Alaska. *Can. J. For. Res.* 11(3): 554-562; **1981**.

## Appendix

### Vegetative Key to the Forest Communities of the Porcupine Plateau Section of the River Drainage, Interior Alaska

A vegetative key was developed based on the results of the TWINSPAN (Hill 1979) analysis. It should be emphasized that this proposed key has not been field tested in the study area and that any attempt to use it outside the area may lead to incorrect conclusions. The initial breakdown was based on overstory age and general cover type (for example—white spruce, black spruce, and hardwood). The vegetative key itself would be located entirely within level I of the preliminary classification system for vegetation of Alaska (Viereck and Dyrness 1980). Levels II through IV are mixed within the structure of the key because the key was based entirely on a vegetative analysis. The final key designation is a level V plant community.

1. Over 75 percent of tree cover contributed by conifer species ..... 2
1. Less than 75 percent of tree cover contributed by conifer species ..... 5
2. Black spruce tree cover at least 25 percent of total, or in young stands at least 25 percent of the seedlings are black spruce ..... 3
2. White spruce tree cover at least 75 percent of total or black spruce seedlings make up less than 25 percent of total ..... 4
3. Average overstory age greater than 40 years ..... Mature black spruce
3. Average overstory age less than 40 years ..... Young black spruce
4. Average overstory age greater than 40 years ..... Mature white spruce
4. Average overstory age less than 40 years ..... Young white spruce
5. Average overstory age greater than 50 years ..... Mature hardwoods
5. Average overstory age less than 40 years ..... Young hardwoods

**Mature Black Spruce**

1. *Rosa acicularis* is present; at least two of the following are absent: *Potentilla fruticosa*, *Betula nana*, *Vaccinium uliginosum*, *Carex* spp., and *Ledum palustre* ..... 2
1. *Rosa acicularis* is absent; at least two of the following are present: *Potentilla fruticosa*, *Betula nana*, *Vaccinium uliginosum*, *Carex* spp., and *Ledum palustre* ..... 7
2. *Arctostaphylos uva-ursi* is present with a cover value greater than 5 percent or *Cyperaceae* is present with a cover value greater than 10 percent ..... 3
2. If *Arctostaphylos uva-ursi* is present with cover greater than 5 percent, then *Cyperaceae* is absent ..... 4
3. *Arctostaphylos rubra* is absent and overstory cover less than 25 percent ..... BS21
3. *Arctostaphylos rubra* is present with a cover value of at least 10 percent ..... WSBS1
4. Two of the following species are present: overstory *Picea glauca*, *Linnaea borealis*, and *Cladonia rangiferina* and at least 60 percent overstory cover ..... 5
4. Less than 60 percent overstory cover and/or *Linnaea borealis* is absent ..... 6
5. At least one of the following is present: *Arctostaphylos rubra* or *Empetrum nigrum*; and at least two of the following are absent: *Alnus crispa* greater than 10 percent, *Graminae*, *Rosa acicularis*, and *Equisetum* spp. ..... WSBS2
5. At least two of the following are present: *Alnus crispa* at least 10 percent cover, *Graminae*, *Rosa acicularis*, and *Equisetum* spp.; and at least one of the following is absent: *Arctostaphylos rubra* or *Empetrum nigrum* ..... BS1

6. At least two of the following are present: *Equisetum* spp., *Betula nana*, and *Alnus crispa* ..... BS12
6. At least two of the following are absent: *Equisetum* spp., *Betula nana*, and *Alnus crispa* ..... BS10
7. Overstory and seedling black spruce with at least 10 percent cover and at least two of the following are absent: *Betula nana*, *Carex* spp., and *Ledum palustre* ..... 8
7. At least two of the following are present: *Betula nana*, *Carex* spp., and *Ledum palustre* ..... 10
8. Overstory cover less than 60 percent and at least three of the following are present: *Vaccinium uliginosum* with cover greater than 5 percent; *Cetraria* spp., *Salix glauca*, *Cladonia rangiferina*, and *Peltigera* spp. ..... WSBS10
8. Overstory cover greater than 60 percent and *Vaccinium uliginosum* with cover greater than 5 percent ..... 9
9. Tall shrub layer contains *Salix* spp. with a cover value of 10 percent and at least 2 percent *Equisetum* spp. ..... WSBS4
9. Tall shrub layer is poorly developed with less than 10 percent cover of *Salix* spp., and no white spruce ..... BS2
10. *Potentilla fruticosa* is present with *Salix* spp., cover less than 5 percent in the low shrub layer ..... 11
10. *Potentilla fruticosa* is absent; *Salix* spp. are present in the tall shrub layer and have a cover value greater than 5 percent in the low shrub layer ..... WSBS3
11. *Carex* spp. present with at least 5 percent cover and *Cetraria* spp. with less than 5 percent cover ..... BS11
11. *Carex* spp., if present, have a cover value of less than 5 percent and *Cetraria* spp. are present with greater than 5 percent cover ..... WSBS11

<b>Young Black Spruce</b>	1. Two of the following four species are present: <i>Rosa acicularis</i> , <i>Shepherdia canadensis</i> , <i>Arctostaphylos uva-ursi</i> , and <i>Salix bebbiana</i> ; <i>Betula nana</i> is absent .....	2
	1. Two of the above four species are present, and <i>Betula nana</i> is present .....	8
	2. White spruce seedlings are present, and <i>Shepherdia canadensis</i> is present with at least 5 percent cover .....	3
	2. Overstory black spruce is present with a cover value of at least 2 percent .....	6
	3. <i>Arctostaphylos rubra</i> and <i>Vaccinium vitis-idaea</i> are present with at least 2 percent cover, and white spruce overstory is present .....	4
	3. At least two of the above three species are absent .....	5
	4. <i>Arctostaphylos uva-ursi</i> is present with a cover value of less than 2 percent and <i>Potentilla fruticosa</i> is present .....	BSY14
	4. <i>Arctostaphylos uva-ursi</i> is present with a cover value greater than 2 percent .....	WSBSY2
	5. Moss and lichen layer cover with at least 33 percent tree litter .....	WSBSY12
	5. Less than 33 percent tree litter .....	ABY1
	6. At least 10 percent cover of <i>Vaccinium vitis-idaea</i> .....	7
	6. Less than 10 percent cover of <i>Vaccinium vitis-idaea</i> .....	BSBY2
	7. Overstory paper birch is present .....	BSBY1
	7. Overstory paper birch is absent .....	WSBSY2
	8. <i>Carex</i> and <i>Ledum palustre</i> are absent; at least 5 percent cover of <i>Equisetum</i> or <i>Arctostaphylos uva-ursi</i> .....	ABSY1
	8. <i>Equisetum</i> or <i>Arctostaphylos uva-ursi</i> , if present, has less than 5 percent cover and two of the following are present: <i>Carex</i> spp., <i>Ledum palustre</i> , and <i>Vaccinium vitis-idaea</i> .....	9

9.	At least 2 percent cover of <i>Betula nana</i> .....	10
9.	If present, <i>Betula nana</i> has less than 2 percent cover .....	11
10.	<i>Vaccinium uliginosum</i> is present, and <i>Carex</i> spp. are absent .....	WSBSY10
10.	<i>Carex</i> spp. are present, and <i>Vaccinium uliginosum</i> is absent .....	BSY11
11.	<i>Dicranum</i> sp. cover is greater than 2 percent, and <i>Rosa acicularis</i> cover is less than 2 percent .....	BSY13
11.	<i>Rosa acicularis</i> cover is greater than 2 percent, and <i>Dicranum</i> sp. cover is less than 2 percent .....	BSY1
<b>Mature White Spruce</b>	1. <i>Cetraria</i> sp., <i>Parmelia</i> sp., and <i>Hylocomium splendens</i> are present, and less than 10 percent cover of willow is in the tall shrub layer .....	2
	1. At least 10 percent willow cover in the tall shrub layer and no <i>Cetraria</i> sp., <i>Parmelia</i> sp., or <i>Hylocomium splendens</i> in the moss and lichen layer .....	6
	2. An upland site with no <i>Cetraria</i> sp., <i>Parmelia</i> sp., or <i>Shepherdia canadensis</i> .....	WS6
	2. <i>Cetraria</i> sp., <i>Parmelia</i> sp., or <i>Shepherdia canadensis</i> is present in the understory .....	3
	3. <i>Salix bebbiana</i> is absent as a tall shrub; <i>Arctostaphylos uva-ursi</i> , <i>Equisetum</i> spp., <i>Lupinus</i> spp., and <i>Vaccinium vitis-idaea</i> are present in the herbaceous layer .....	4
	3. <i>Salix bebbiana</i> is present as a tall shrub .....	5
	4. Overstory canopy cover is less than 60 percent, or cover of <i>Equisetum</i> sp. is greater than 10 percent .....	WS11
	4. Overstory canopy cover is greater than 60 percent, and <i>Linnaea borealis</i> cover is greater than 2.5 percent .....	WS7

5.	Overstory cover is greater than 60 percent, and cover of <i>Rosa acicularis</i> is less than 10 percent .....	WS1
5.	Overstory cover is less than 60 percent, and cover of <i>Rosa acicularis</i> is greater than 10 percent .....	WS10
6.	<i>Rosa acicularis</i> cover is greater than 25 percent, and the cover of <i>Alnus crispa</i> is greater than 1 percent .....	7
6.	<i>Alnus crispa</i> is absent, and <i>Shepherdia canadensis</i> and <i>Arctostaphylos rubra</i> are present .....	8
7.	<i>Salix</i> spp., <i>Arctostaphylos uva-ursi</i> , and seedling <i>Picea glauca</i> are absent .....	WS4
7.	<i>Salix</i> spp., <i>Arctostaphylos uva-ursi</i> , and seedling <i>Picea glauca</i> are present .....	WS2
8.	<i>Populus tremuloides</i> saplings are present, and <i>Salix</i> spp. are present in the low shrub layer .....	WS3
8.	<i>Picea glauca</i> seedling cover is greater than 10 percent; <i>Equisetum</i> spp. are present with cover greater than 2.5 percent .....	WS5
<b>Young White Spruce</b>	1. Birch seedling cover is greater than 5 percent, and white spruce overstory cover is less than 2 percent .....	2
	1. Birch seedling cover is less than 5 percent, and white spruce overstory cover is greater than 2 percent .....	3
	2. <i>Ledum palustre</i> may be present and <i>Mertensiana</i> spp. absent .....	WSY11
	2. <i>Ledum palustre</i> is absent, and <i>Mertensiana</i> spp. are present .....	WSBY1
3.	<i>Arctostaphylos uva-ursi</i> is present with or without <i>Potentilla fruticosa</i> .....	WSY5
3.	<i>Arctostaphylos uva-ursi</i> and <i>Potentilla</i> <i>fruticosa</i> are absent .....	WSY2

<b>Mature Hardwood Types</b>	1. <i>Equisetum</i> has a cover value of at least 2 percent under a balsam poplar overstory cover greater than 10 percent .....	BP1
	1. Overstory balsam poplar is less than 10 percent .....	2
	2. At least 2 percent of overstory is white spruce with at least 2 percent <i>Peltigera</i> spp. and <i>Arctostaphylos rubra</i> .....	6
	2. At least 50 percent cover of overstory aspen with less than 2 percent white spruce and at least 10 percent <i>Arctostaphylos uva-ursi</i> .....	3
	3. At least 5 percent overstory cover of both balsam poplar and aspen with no <i>Arctostaphylos uva-ursi</i> in understory .....	APB1
	3. Less than 2 percent overstory cover of balsam poplar or greater than 2 percent cover of <i>Arctostaphylos uva-ursi</i> .....	4
	4. More than 2 percent overstory is balsam poplar cover, and more than 2 percent cover is <i>Arctostaphylos uva-ursi</i> .....	BP2
	4. Less than 2 percent overstory cover of balsam poplar .....	5
	5. <i>Arctostaphylos uva-ursi</i> is present with a cover value of at least 25 percent, and overstory aspen cover is less than 60 percent .....	A10
	5. Overstory aspen cover is greater than 60 percent, and <i>Arctostaphylos uva-ursi</i> cover is less than 25 percent .....	A1
	6. <i>Galium boreale</i> is present, and <i>Shepherdia canadensis</i> is absent in the understory .....	WSB1
	6. <i>Shepherdia canadensis</i> is present .....	7
	7. <i>Epilobium</i> sp., <i>Pyrola</i> spp., and <i>Linnaea borealis</i> are the most dominant herbaceous species, and <i>Arctostaphylos uva-ursi</i> cover is less than 2 percent .....	AWS1
	7. <i>Arctostaphylos uva-ursi</i> has a cover value greater than 2 percent .....	AWS2

<b>Young Hardwood Types</b>	1. Black spruce seedlings and <i>Alnus crispa</i> or <i>Empetrum nigrum</i> are present .....	2
	1. Black spruce seedlings are absent .....	3
	2. Birch seedlings are present .....	ABSY1
	2. Birch seedlings are absent .....	ABSY2
	3. Overstory balsam poplar cover is at least 2 percent, and <i>Pyrola</i> spp. are present .....	BPY1
	3. Aspen is present in the overstory, and at least 5 percent is aspen regeneration and 10 percent is cover of <i>Shepherdia canadensis</i> .....	4
	4. At least 2 percent of cover is white spruce regeneration, and 33 percent in the tall shrub layer is willow; no <i>Arctostaphylos uva-ursi</i> is present .....	AWSY1
	4. <i>Arctostaphylos uva-ursi</i> and some Graminae are present .....	5
	5. At least 2 percent cover is white spruce regeneration, 33 percent cover is willow in the tall shrub layer, and <i>Arctostaphylos uva-ursi</i> is present in the herbaceous layer .....	AWSY2
	5. Less than 2 percent cover is white spruce regeneration, and 33 percent is tall willow .....	6
	6. Less than 2 percent is overstory balsam poplar with at least 10 percent overstory aspen .....	AY10
	6. Equal mix of balsam poplar and aspen either in the overstory or as seedlings .....	ABPY1

**Yarie, John.** Forest community classification of the Porcupine River drainage, interior Alaska, and its application to forest management. Gen. Tech. Rep. PNW-154. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 68 p.

The forest vegetation of 3 600 000 hectares in northeast interior Alaska was classified. A total of 365 plots located in a stratified random design were run through the ordination programs SIMORD and TWINSPLAN. A total of 40 forest communities were described vegetatively and, to a limited extent, environmentally. The area covered by each community was similar, ranging from 0.29 to 4.29 percent. A large number of mixed spruce communities were described and suggested to be the result of the study area's proximity to the northern limit of black spruce (*Picea mariana* (Mill.) B.S.P.). Average aboveground tree biomass and productivity were estimated for each community. Values for trees ranged from 0.2 kilogram per square meter aboveground biomass and 4.0 grams per square meter per year mean annual increment for a woodland black spruce community to 23.4 kilograms per square meter and 195 grams per square meter per year for a closed white spruce community. The potential productivity of the study area was estimated on the basis of 100-percent stocking of each community with trees. A total of 42.9 percent of the area was estimated to have potential to support commercial forests.

Keywords: Classification (forest communities), biomass, Alaska (Porcupine River drainage).

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# Procedures for Establishing and Maintaining Permanent Plots for Silvicultural and Yield Research

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## **Abstract**

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This paper reviews procedures for establishing and maintaining permanent plots for silvicultural and yield research; discusses purposes, sampling, and plot design; points out common errors; and makes recommendations for research plot designs and procedures for measuring and recording data.

**Keywords:** Plot analysis, permanent sample plots, tree measurement, sample plot design.

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## **Introduction**

### **Background**

Rational forest management requires information on production and patterns of development of forest stands under current and future stand conditions and management regimes, as a basis for managerial choices, economic decisions, and field application of chosen regimes. This information comes from observation of forest stand development and from silvicultural experiments.

Estimates of present stand volumes and growth rates usually come from forest inventories. The planned forest of the future will, however, often be quite different from the present forest. Present average growth rates do not tell us what we can expect from the future forest, nor do they provide guides to desirable management regimes or a basis for choice among possible management regimes. These require estimates of the behavior of managed stands, including response to such management measures as spacing control, thinning, and fertilization. Such estimates are provided by silvicultural experiments designed to determine the relationships between growth, stand conditions, and stand treatments; and by various types of yield tables and stand simulators which attempt to combine these relationships into generally applicable systems for estimating behavior and production of future stands.

From about 1920 to the 1940's, normal yield tables were developed for many major species. Procedures for constructing normal yield tables from temporary plot measurements in well-stocked wild stands were worked out and fairly well standardized. During the next two decades, relatively little new work was done on yield tables, but many silvicultural field experiments were established.

Since the early 1960's, there has been renewed interest and activity in yield research. This was stimulated by the advent of the computer, the availability of increasing amounts of data from thinning and fertilization experiments, and an urgent need for silvicultural guides and yield estimates applicable to the growing area of young stands and to increasingly intensive management. The former distinction between yield research and silvicultural research is no longer clear, and the new yield tables are various types of simulation models that estimate growth rates and yields for a range of possible management regimes, using the results of silvicultural research.

Estimates of growth rates and treatment responses are wanted for stand conditions and stand treatments that do not yet exist on large operationally developed forest areas. These estimates must therefore be based on silvicultural experiments and small experimentally treated areas. Most of the present information on thinning and fertilization has been so developed. There have been many studies showing response at particular locations, usually reported as case studies. But until recently, there have been relatively few attempts to combine such information into regionally applicable quantitative generalizations.

Such generalized estimates are badly needed. Few individuals or organizations possess a data base adequate for the purpose, and there is much to be gained by pooling data in cooperative efforts among research workers and research organizations. This requires compatibility of and comparable reliability in data collected by different individuals and organizations.

Certain defects that are repeatedly encountered severely limit or destroy the usefulness of much data obtained at high cost in time and money.

1. Documentation is often inadequate. Records of procedures, stand measurements, and stand treatments are incomplete, poorly organized, or contradictory.
2. Plots are often excessively small or are installed without buffers between adjacent treatments, or both.
3. Height measurements are frequently inadequate in number, distribution, or accuracy, and have sometimes been omitted altogether.
4. Measurements are often omitted for trees below some arbitrary "merchantable" size, which results in truncated diameter distributions and statistics that cannot be compared with other data.
5. Estimates of tree and stand ages are often inaccurate. Sampling is frequently inadequate, definitions are ambiguous or inconsistent, and procedures have not been documented.
6. Initial stand conditions, prior to treatment, are often not recorded.
7. Plot areas are often unreliable because of poor plot surveys and poor records.
8. Changes are sometimes made in treatments, plot sizes, or measurement procedures for reasons of immediate expediency in fieldwork, without consideration of effects on later analyses.
9. Data codes and measurement standards are often inconsistent or incompatible. This prevents use of a common set of computer programs or pooling of data among organizations or individuals, without costly and time-consuming conversions and loss of information.

## Purpose

This paper discusses items that should be considered by anyone planning or undertaking establishment and measurement of field plots in silvicultural experimentation, or for construction of yield tables. It is concerned primarily with design and measurement of individual plots. The larger questions of experimental design in general, and of overall sampling design, are touched on only as they relate to plot procedure.

Procedures for establishing and maintaining such research plots have been discussed in a number of past publications, including Decourt (1973), Forestry Commission (1979), Hummel and others (1959), Robertson and Mulloy (1944, 1946), Synnott (1979), and USDA Forest Service (1935). There are also various in-house manuals that are not generally available. These contain much information of value; however, some procedures discussed are now out of date, and many manuals are oriented specifically to the needs and procedures of individual organizations and projects.

Installation and maintenance of permanent plots are not simple tasks. This paper is not intended to be a complete, detailed manual of field procedure. Rather, it is intended as an aid for those preparing procedural specifications. It should help them to avoid repetition of past mistakes by calling attention to decisions needed in the planning stage of a research study. It should help them to provide some standardization and compatibility between data sets. It may give field personnel insight into the reasons behind procedures, and possible alternatives.

Portions of the discussion may appear to be mere repetition of the obvious. Experience, however, shows that many obvious points become obvious only in the analysis stage, when it is too late to correct mistakes made in establishing and measuring plots.

The discussion is generally in terms of fixed area remeasured plots and even-aged stands with one principal species. Historically, these are the plot type and stand condition most often used in silvicultural experiments and in construction of managed stand yield tables; however, many of the same ideas and principles apply to studies using point sampling and to other stand conditions. Although aimed at research applications, they may also suggest possible modifications in inventory and stand examination procedures to make them more compatible with information developed from research.

Necessarily, recommendations made in this paper often represent informed opinion and the author's best judgment rather than established fact.

## Data Sources

Approaches to silvicultural and yield estimation problems are influenced by (1) specific objectives, (2) nature of the forest (even aged vs. uneven aged, pure vs. mixed species), (3) data already available, and (4) feasibility of acquiring new data.

Data may come from research plots installed to secure information on a particular relationship, from research plots designed to sample specified stand conditions over a region, from existing research plots originally installed for these or other purposes, from management inventories, or from some combination of these.

Inventory data are often available in large quantity, and they provide a representative sample of the existing forest. They are usually the best basis for short-term projections; they have not generally proved satisfactory for other purposes, for several reasons.

The small plots used in many inventories are subject to unknown edge effects. Usual procedures provide only rough estimates of such attributes as age and height for the individual plot and frequently omit or inadequately sample stems below some arbitrary and fairly large diameter. Such data are well suited to estimation of stratum means (their designed objective) but are poorly suited to estimation of treatment responses or the regression relationships used in stand simulation.

When estimating treatment effects, comparing potential treatment regimes, and making long-term estimates for future managed stands, one is commonly dealing with conditions that as yet exist only on small areas and very restricted experimental installations. These are not sampled adequately, if at all, by management inventories. If sampled, the uncontrolled variation present usually prevents satisfactory evaluation of treatment response.

For these and similar reasons, most silvicultural research and much yield research are based on plots established independent of management inventories.

## **Plot Classification**

Field plots used in silvicultural and yield research can be classified into three groups:

1. Temporary (single-measurement) plots.
2. Temporary plots, with supplementary growth information.
3. Permanent (remeasured) plots.

### **Temporary Plots**

The normal yield tables of the 1930's were generally based on temporary plots. Ages, diameters, and heights were measured, but no direct information was obtained on current growth rates and mortality rates.

Such plots still have their uses, but they will not be further considered here. They do not provide the information on growth and mortality required for most modern yield tables.

### **Temporary Plots, With Supplementary Growth Information**

Additional measurements obtained from increment cores and stem analyses can provide information on growth rates of trees on temporary plots. This information can be extrapolated for short periods to provide the periodic growth values or estimates of current growth rates needed for some types of analyses. This is a common procedure in inventories in which such procedures provide some growth information at less cost and without the delay involved when permanent plots are used. Similar methods can be used to obtain growth data for construction of yield tables and stand simulators, by procedures such as those discussed by Curtis (1967b), Myers (1966, 1971), and Vuokila (1965).

Although information may be obtained quickly by such methods, precision comparable to that of permanent plot methods is not cheap, if attainable at all. The accurate determination of diameter growth required in research studies is not easy. Except in young stands of species with annual internodes which can be directly measured from the ground, height growth estimates can be obtained only by laborious and destructive stem analyses; or by assuming (perhaps incorrectly) that preexisting site index curves are a correct representation of height growth. Information on mortality is obtainable only in the form of subjective estimates of year of death of dead trees on the plot. Stand treatment information is usually confined to measurement of visible stumps and rough estimates of date of cutting. No information can be obtained for stand conditions and treatments not present in the existing forest.

It is possible, however, to construct yield estimates from this type of data, and such data are often useful as a means of supplementing existing permanent plot data.

### **Permanent (Remeasured) Plots**

Much past and present research uses "permanent" plots, which are established and measured at the start of an investigation and subsequently remeasured at intervals over a period of a few to many years. Such plots are expensive and represent a long-term commitment of resources which is unpopular with many administrators. Permanent plots can provide data of superior accuracy and information obtainable in no other way, however.

For the period of observation, permanent plots provide points in a real growth series, as opposed to artificial growth series constructed from single measurements of stands thought to represent successive stages in development. Over an extended period of years, the record of actual development of individual stands provides a standard against which estimates can be compared. Characteristics and development of individual trees can be followed over time. Such plots provide a complete history of stand development and stand treatment, response to treatment, and actual stand damage and mortality—information not obtainable from other types of plots. When observations are continued over many years, variations in growth caused by short-term climatic fluctuations should be compensating. And, for demonstration purposes, the on-the-ground examples and historical record of treatment and response which they provide are more convincing to field foresters than any amount of statistical analyses and projections of temporary plot values.

This paper is primarily concerned with permanent plots, although many of the principles and recommendations given also apply to temporary plots with supplementary growth information.

## Some Sampling Considerations

A first step in any sampling scheme is to define the population about which inferences are to be made, in terms of such associated characteristics as physical location, site quality, stand origin, age class, species composition, management treatment, and freedom from destructive agents. For many research studies, there is no need to sample conditions that will be excluded from the forest under anticipated future management. Thus, silvicultural experiments and yield studies rarely include very old and decadent age classes. Stands severely injured by disease, insects, or climatic agents are usually excluded on grounds that, under management, such stands will be terminated.

Sample selection is relatively straightforward in management inventories, where the population consists of all presently existing stands and the primary objective is to estimate stratum means. It is less straightforward in silvicultural studies intended to develop estimates of growth of future managed stands. In the latter case, one often seeks inferences about some largely hypothetical population of future managed stands, which may differ considerably from the present forest. The primary objective is often not to determine means of volume or basal area for some category of stands, but to estimate coefficients of functions relating growth to current stand values and possible treatments. The conditions of most interest for this purpose may exist only on certain small areas. Some conditions and treatments must be created on newly established experimental plots. Some combinations of stand condition and treatment can be produced only by an extended period of management; these cannot be sampled directly, and estimates must be based on extrapolations from the most nearly analogous conditions available.

Yield studies often use regression analyses of unreplicated plots, established in the portions of the existing forest that meet stated specifications of age, species composition, health, density or treatment category, and relative uniformity in stand and site conditions. Plot location within suitable areas is often done subjectively; the observer attempts to select a plot representing either an average condition for the stand or the observer's conception of conditions likely under future management. An alternative, more objective, and statistically more defensible approach in such studies is to select and delineate stands that meet the required specifications and then to locate the plot(s) within them by some random or systematic sampling procedure.

Such stands should be deliberately selected to obtain as wide a distribution of the predictor variables as possible, consistent with study objectives and expected application of the model. As an example, many predictors of growth are regression models that involve age and some measure of density. A statistically desirable selection would insure that the plots include a wide range of densities for each age class. As sample selection proceeds, the distribution of age and density can be indicated in a two-way table and an effort made to fill all cells as equally as feasible. Such a selected sample yields a rectangular distribution of age and density; in subsequent regression analyses, it will provide a better assessment of effects of the predictor variables, and better predictions near the margins of the range of data.

In silvicultural experiments, treatments are usually replicated at a given location in accordance with some specified experimental design. This provides an estimate of experimental error and allows statistical analysis of results at that location. Often, the experimenter's primary interest is in defining some specific relationship, such as response to fertilizer dosage or to density level. To minimize the experimental error, the experimenter will then impose stringent requirements on initial homogeneity and comparability of plots within that installation. Meeting this requirement of close comparability of initial conditions among plots generally requires that the plots be subjectively located, with subsequent random assignment of treatments.

Many yield studies use regression analyses of plots selected in chosen strata of the existing population, supplemented with plots from silvicultural experiments. The latter furnish information on conditions and treatments not available in the existing forest and may provide guides to the form and nature of certain relationships. Considerations of time, cost, and availability of data often force the analyst to use data that are not completely comparable or compatible in method of plot selection and standards of measurement, and treatments may or may not be replicated at a particular location. Stringent stand uniformity requirements and close control of treatments, which are necessary for identification and measurement of treatment effects in silvicultural experiments, may lead to estimates that require adjustment for operational use (Bruce 1977).

Valid conclusions applicable on a regional basis also require that additional installations be distributed over a range of site conditions, initial stand conditions, and geographic locations that include various unmeasured and possibly unrecognized factors affecting growth.

Most silvicultural experiments and yield studies recognize the need for replication at a given location if conclusions are to be drawn for that location and the need to sample the range of stand and site conditions if conclusions are to be drawn on a regional basis. The need to include a range over time is less generally recognized, however.

Growth of forests varies from year to year and decade to decade because of variation in climatic conditions and sporadic occurrence of widespread stand injuries and cone crops. In some instances, these fluctuations can be extreme (Keen 1937, Reukema 1964). Mortality tends to be clustered in both time and space because it is associated with climatic extremes and with the occurrence of windstorms and insect and disease outbreaks.

It is therefore risky to base estimates of expected growth on observations of growth, mortality, and treatment response made in a single short time period. Although little can be done to allow for possible long-term trends, short-term variations will average out when the basic data represent a series of time periods rather than a single short period. This is one major value of long-term permanent plot observations and of the accumulation over time of compatible data collected by consistent procedures.

## **Plot Installation**

Well-designed permanent plots maintained and repeatedly remeasured over time become more valuable with increasing length of record. Many times they are valuable for purposes other than the study for which they were installed, and for purposes not anticipated by the person who installed them.

Long-term permanent plot data are often analyzed by someone other than the original investigator. Analytical techniques and objectives change over time, and there can be no certainty that the computational procedures and analyses foreseen at the time the plots were established will be those judged most suitable at the time of later analyses.

Therefore, procedures and data should be as complete and general as possible. Shortcuts that will later limit analyses to specific summarization and analysis procedures should be avoided. Experience shows that such shortcuts usually result in later costs and loss of information far more important than small immediate savings in field time. It should be anticipated that details of site classification, volume computation, and similar procedures will change, and the data should be adequate to permit summarization and analysis by any generally applicable procedure.

## **Plot Configuration**

The plot is the basic unit of observation. It is usually a single area delineated on the ground. It may consist of a cluster of subplots (or points, if variable radius plots are used) arranged randomly or systematically within the treatment area or stand, with cluster totals treated as the basic values for analysis. In clumped or irregular stands, such clustered subplots may be preferable to single larger plots and more consistent with later management application of results.

Fixed area plots can be any shape but are usually circles or squares, which minimize perimeter per unit area and, hence, edge effects and required area of buffer. Circles are convenient for very small plots, but accurate location of the perimeter becomes difficult for larger plots. The straight borders of squares and rectangles lend themselves to accurate location and marking of corners and borders. Corners of squares are easily located with compass and tape by measuring diagonals from an initial plot center (fig. 1); subsequent measurement of boundaries provides a check on errors. Rectangles are sometimes advantageous where there is a pronounced site gradient (as on steep slopes) and the long axis of the rectangle can be oriented at right angles to the gradient to reduce variation within the plot. Fieldwork is simplified and blunders are reduced if a standard plot shape and layout procedure are adopted and used whenever the situation permits.

**RECOMMENDATION:** The square plot is generally the most useful and convenient for research studies.

Some special considerations arise in regularly spaced plantations, which sometimes influence positioning, orientation, and exact size of plots.

In some research plantations established with very close control of spacing, it is feasible to use a square or rectangular plot positioned so that its sides lie midway between rows, thereby insuring that plot area is identical with the growing space available to the trees on the plot. This is desirable when feasible and will produce plots with areas that differ slightly from the simple fractional acres or fractional hectares generally used (fig. 2).

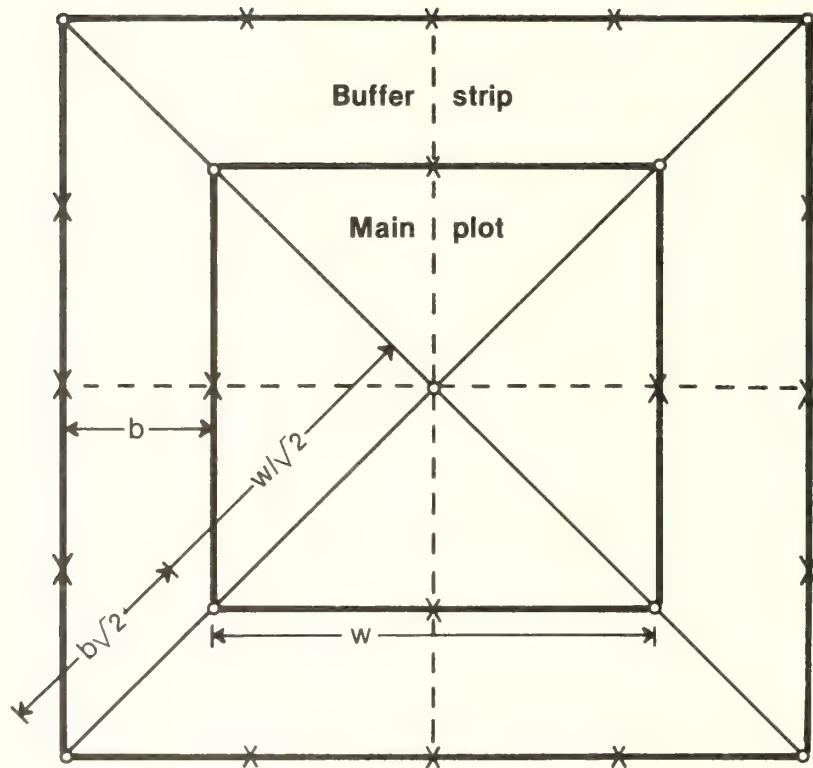
A more common situation is that in which an existing plantation has spacing not sufficiently regular to allow positioning the plot with sides midway between rows, but still sufficiently regular that position and orientation of the plot can result in a plot area that differs appreciably from the total growing space available to the trees on the plot. This in turn will bias all growth computations. One means of reducing such bias is to orient the plot so that its sides intersect the planting rows at an angle of 20° to 30° (fig. 3).

Variable radius plots (points) may also be used for permanent plots. Single points are not a usable sampling unit for research purposes, since they include too few trees to provide satisfactory estimates either of growth rate or of the stand attributes used as predictors of growth. A systematic arrangement of 5 to 10 points within a stand can be used, however.<sup>1</sup> Variable radius plots are more consistent with commonly used inventory procedures than are fixed area plots, and they have the well-known advantage that sampling proportional to basal area concentrates the measurements on the trees of larger size and (usually) higher growth rates.

Because variable radius plots include few trees from the smaller diameter classes and information is generally also needed for these, it is usually necessary to combine the variable radius plot with a concentric fixed area plot on which all trees below a specified limiting diameter are recorded. The fixed area plot size should equal the size of the variable radius plot for the specified limiting diameter.

The fact that trees initially outside the variable radius plot grow "onto" the plot as they increase in size ("ongrowth" trees) complicates computations and introduces irregularities in growth estimates for successive periods, which are not present with fixed area plots (Martin 1982, Myers and Beers 1968).

<sup>1</sup> Hann, David. Development of growth and yield information for the mixed conifer zone of southwest Oregon. Study plan on file at Oregon State University, Corvallis, Oregon. 1981.



○ = permanent stakes at corners

✗ = temporary stakes (optional) aid in locating lines and in subdividing plot for tagging trees and measurement and selection of site trees

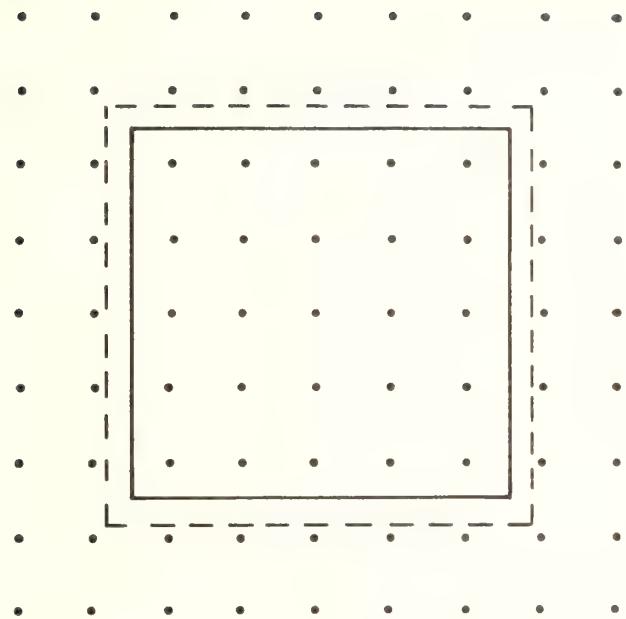
w = length of side of main plot

$w\sqrt{2}$  = length of semidiagonal of main plot

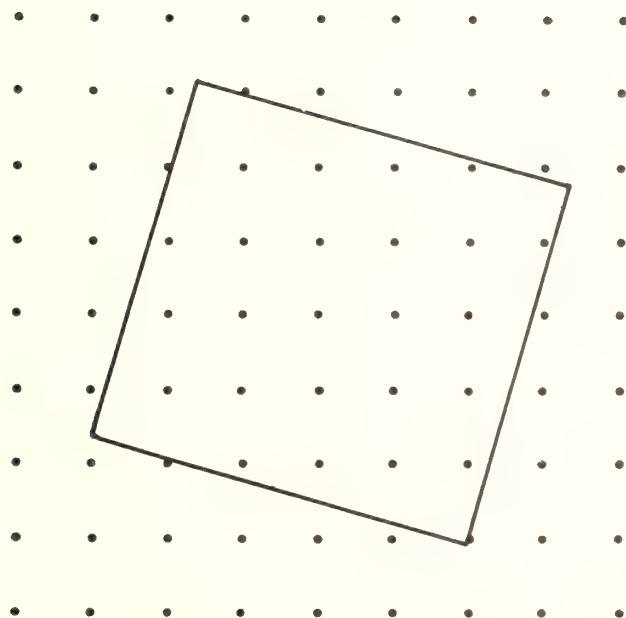
b = width of buffer strip

$b\sqrt{2}$  = extension of semidiagonal to corner of buffer

Figure 1.—Typical layout of a square plot.



• Figure 2.—Position of plot borders in a plantation. Correct position (solid line) gives unbiased estimates of growth per unit area. Incorrect position (dashed line) gives biased estimates of growth per unit area.



• Figure 3.—Orienting plot at an angle to rows in plantation reduces bias in estimates of growth per unit area associated with position of plot borders.

Such a cluster of points usually extends over more physical area than a typical fixed area plot serving a similar purpose. This may be an advantage or a disadvantage, depending on the nature and purpose of the study. It may be difficult to provide the buffers and replication needed when several treatments are to be applied within a limited area in a silvicultural experiment. Over an extended observation period, an initially reasonable spacing of points can lead to variable plots that overlap or extend into adjacent dissimilar treated areas. Because the point cluster extends over a greater area, however, it may be more representative of conditions existing on a stand basis and may be more consistent with data arising from typical stand examination procedures.

Variable radius plot (point) clusters are best suited to studies that sample preexisting stand conditions, or where treatments are applied to relatively large areas, rather than to typical silvicultural treatment experiments.

#### **Plot Size**

Plot size is influenced by intended purpose, by stand conditions, by expected duration of the study, and by cost considerations.

The criteria for suitable plot size in a research study are not the same as in an inventory. Frequently, an inventory aims to determine average values of certain variables (such as volume) for given strata, as means of plots falling in those strata. Within limits, increased plot numbers can compensate for increased variability associated with smaller plots, and estimated means are unbiased regardless of plot size.

Many research studies, however, use regression equations to estimate individual tree or plot growth as functions of current stand values of individual plots. Very small plots will produce highly variable estimates and can lead to biased estimates of regression coefficients as a result of edge effects and bias in subjective location of plots.

Variability increases with decreasing plot size, and plots that are excessively small relative to the pattern of within-stand variation will produce a considerable range of values for variables such as density and volume (Smith 1975). If field plots are then subjectively located for apparent uniformity and full stocking (a common procedure in field experiments), the resulting values may be higher than are realistically attainable on a stand basis. If plots are systematically located, observed growth on the plot will represent in part an effect of adjacent, unmeasured, differing stand conditions. High density plots will grow well because they are using adjacent growing space. Low density plots will grow relatively poorly because of the competition of adjacent dense groups of trees.

Small plots are also likely to bias mortality estimates. In many studies, plots which lose a substantial part of their stocking to mortality between two successive measurements are assumed to represent instances of "catastrophic mortality" and are discarded. On small plots, however, death of even a few trees in a given period will result in large negative increments. The analyst cannot tell whether this represents merely a few trees whose loss is insignificant in overall stand development, or a major disaster; the variation introduced can totally obscure any relationship between growth response and stand treatment. The plot must therefore be discarded. The result is not merely highly variable estimates of mortality, but estimates of mortality and of the relation of mortality to stand conditions and treatment which are biased by the plot selection process.

Excessively small plots can be expected to give erratic values for stand statistics and poor correlations of increment with site and stand attributes; they may also give biased estimates of the increment-stand density relationship (Jaakola 1967). Such effects will generally be more serious in mechanically located plots without buffers (as in inventories) than in research plots established in selected stand conditions (usually chosen for homogeneity) and provided with suitable buffers, so that edge effects are reduced.

Although the effects of plot size on yield analyses have not been thoroughly investigated, a number of rules of thumb for desirable size of fixed area plots are given in the literature.

Early U.S. investigators commonly recommended plot sizes that would include at least 100 stems exclusive of understory at the end of the experiment (Bruce 1926; Osborne and Schumacher 1935; USDA Forest Service 1935—still an excellent reference on many aspects of plot installation and measurement; Marckworth and others 1950). Since much of this work was in untreated stands, presumably a somewhat lesser number would be acceptable in the more uniform stand conditions expected in plantations and consistently thinned stands.

Fabricius and others (1936) recommended plots of at least 0.6 acre (0.25 ha), larger in irregular stands. Robertson and Mulloy (1944, 1946) recommended 0.5- to 1.0-acre (0.2- to 0.4-ha) plots. Jeffers (1959) recommended 0.25 to 1.2 acres (0.1 to 0.5 ha) for even-aged pure stands, depending on spacing. Hummel and others (1959) recommended plot sizes of 0.3 to 0.5 acre (0.12 to 0.20 ha) for pure conifers, 0.5 to 1.0 acre (0.2 to 0.4 ha) for mixed stands. The Forestry Commission (1979) recommended plot sizes of 0.25 to 0.5 acre (0.1 to 0.2 ha) for general use, with a minimum of 0.2 acre (0.08 ha) for single plots in conifer plantations, 0.3 acre (0.125 ha) for hardwoods, and 0.1 acre (0.04 ha) in replicated treatment experiments (excluding buffers).

Vuokila (1965) compared coefficients of variation for alternate plot sizes and recommended a size in hectares equal to  $0.01 \times$  (dominant height in meters), which corresponds to a plot size in acres of  $0.0075 \times$  (dominant height in feet). Decourt (1973) recommended the same standard, with the restrictions that minimum plot size should not be less than 0.25 acre (0.1 ha) and that the plot should contain 100 to 200 stems. Hegyi (1973) made a somewhat similar analysis of plot size in three untreated jack pine (*Pinus banksiana* Lamb.) stands. His coefficient of variation curves suggest minimums of 50 to 75 stems per plot and areas of about 0.1 acre (0.05 ha) for these small-diameter stands. Note that these comparisons of coefficients of variation all deal with live stand volumes and basal areas, rather than with increment rates—which are frequently the values of primary interest.

Plot sizes in the general range of 0.25 to 0.5 acre (0.1 to 0.2 ha) have been used in several U.S. and foreign thinning and fertilization studies (Carbonnier and Fries 1976, Clutter and Jones 1980, Hamilton 1976, McEwen 1979).

In 1969, the University of Washington Regional Forest Nutrition Program adopted a minimum plot size of not less than 0.1 acre (0.05 ha), to contain at least 50 stems, plus buffer.<sup>2</sup> The British Columbia Forest Productivity Committee specified a minimum of 0.12 to 0.25 acre (0.05 to 0.1 ha) according to number of stems, but not less than 60 stems, plus buffer.<sup>3</sup>

Recent studies in the Pacific Northwest have frequently used quite small plots—sometimes as small as one-twentieth acre (0.02 ha)—because of difficulty in finding fully comparable stand conditions over an area large enough to allow replication of a series of treatments at a single location.

Our experience (Curtis and others 1981) leads to the conclusion that the very small plot sizes used in some thinning and fertilization experiments are undesirable, and sometimes unusable, as a basis for increment regressions and for estimates of mortality and diameter distributions.

Note that all the rules of thumb given above lead to plot sizes considerably larger than those used in many inventories, even though stands are selected for uniformity. Plots smaller than those used in the University of Washington and British Columbia Forest Service studies cited are clearly undesirable as sources of growth and yield data, and even these have severe limitations for study of diameter distributions and mortality.

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<sup>2</sup> University of Washington. Forest fertilization research in the Douglas-fir region of the Pacific Northwest: research proposal and project description. College of Forest Resources, Seattle. 1969.

<sup>3</sup> British Columbia Forest Service, Forest Productivity Committee. Field manual, balanced installation field programme. Victoria, B.C. 1974.

Consistency among plot sizes in different stand conditions may be obtained by relating a standard number of stems to average diameter or to stand height. Figure 4 gives an example of such a guide, indicating the plot sizes required to include 50 stems in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands of a given average diameter and percentage of normal stand density. (Many thinned stands, for example, would fall between the 50- and 75-percent curves indicated in early thinnings, and near the 75-percent curve at older ages.) Similar guides can also be derived from the relation of number of trees and dominant height, or from the crown area-diameter relationship of open-grown trees. Such guides should be qualified by a minimum number of trees acceptable in the most open stands (minimum of 50 suggested). Generally, a single plot size determined by the most extreme treatment should be used for all plots within an installation.

The preceding discussion applies to relatively uniform even-aged stands of a single species; in many cases cited, to plantations. Mixed species stands and uneven-aged stands will be inherently more variable and will require larger plots—sometimes much larger—to characterize stand structure and growth. (For example, Synnott (1979) recommends 2.47-acre (1.0-ha) plots for mixed tropical forest.)

Although the above discussion applies directly only to fixed area plots, similar considerations apply to variable radius plots. The basal area factor, number of points, and limiting diameter and radius of the concentric fixed area plot should be chosen to include a sufficient number of trees to provide a reasonably smooth diameter distribution and the ability to distinguish "catastrophic" from "regular" mortality. The decision on arrangement and spacing of points should take into account future growth, so that with increase in tree size the variable radius plots will not overlap each other or adjacent dissimilar treatments or conditions, within the anticipated life of the study.

Plots composed of single trees or small groups of trees have their uses for such purposes as determining presence or absence of response, relation of response to individual tree characteristics, pruning studies. Fully satisfactory and generally accepted techniques for expanding such results to a unit area basis are not now available, however.

**RECOMMENDATIONS:** Experimental designs that require large numbers of plots within a single homogeneous stand condition—forcing use of small plots because of the limited size of suitable areas—are not generally feasible for silvicultural and yield research and should be avoided.

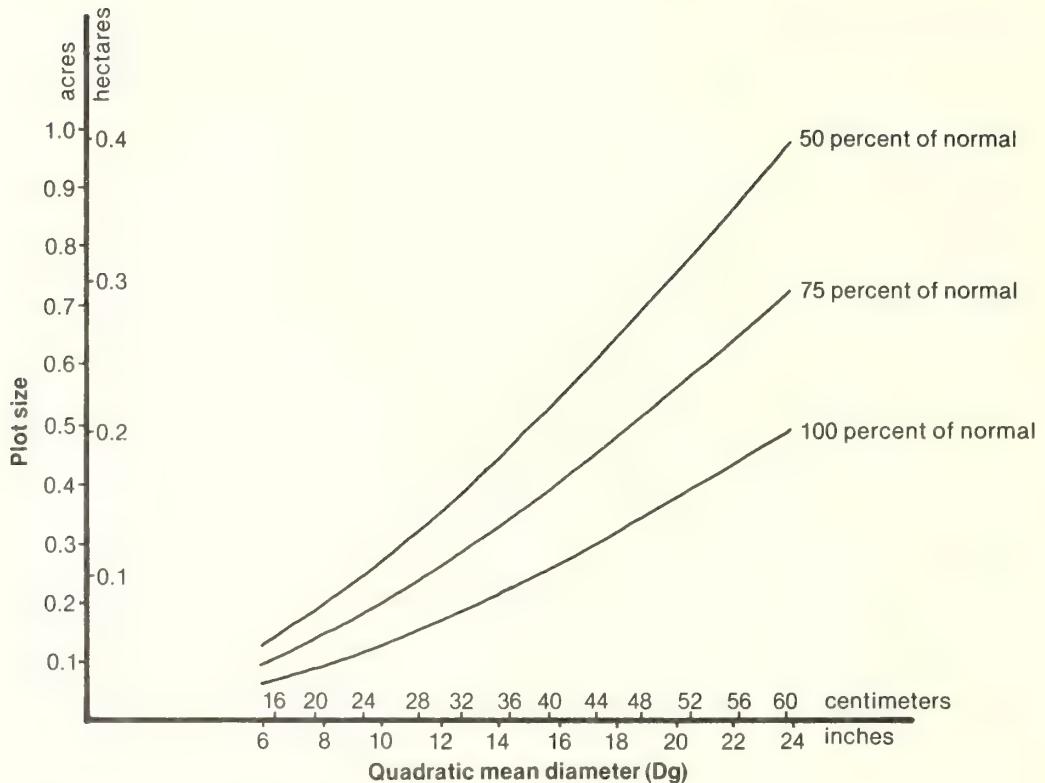


Figure 4.—Plot sizes required to include 50 trees in Douglas-fir stands of given quadratic mean diameter and density expressed as percent of normal. (Percent of normal is here defined as number of trees relative to that in the long-used table 25 in McArdle and others (1961).)

Although no fixed universal standards can be given, required size of plot (or plot cluster) will increase with (1) average tree size and (2) within-stand heterogeneity. Plot size should be selected in relation to the stand conditions expected at the end of the planned period of observation, rather than to initial conditions only. Plot size should be large enough in relation to stem size, number of stems, and pattern of stem distribution that:

- (1) the plot can be regarded as representative of a condition that exists, or could exist, on a stand basis (that is, minor shifts in plot location would not materially alter the plot statistics);
- (2) growth of trees on most of the plot area is little affected by surrounding, possibly unlike, stand conditions;
- (3) sufficient stems are included to provide a reasonably smooth diameter distribution; and
- (4) "catastrophic" mortality can be distinguished from "regular" mortality composed of suppression losses plus occasional death of scattered larger trees.

## **Plot Buffers**

Research plots should be surrounded by a buffer strip of comparable initial conditions, which receives identical treatment. This insures that growth of the plot is not influenced by adjacent, unlike stand conditions and treatments. It also provides for the possibility of future destructive sampling of individual trees for such purposes as determination of past height growth patterns and wood quality studies, without destruction of the plot proper.

Adjacent stand density differences have an effect on microclimate on the plot. It is well known that root systems extend for considerable distances and that root grafting and physiological linkage with nearby trees are common. Root systems of onplot trees will exploit water and nutrients available adjacent to the plot, and vice versa. Therefore, onplot growth is likely to be influenced by adjacent changes in site conditions and stand density. Adjacent fertilizer treatments may affect growth of unfertilized plots through root systems that extend across plot boundaries, through downslope movement of soil water, and through litter fall from fertilized trees onto unfertilized areas.

Failure to provide adequate buffers will tend to produce underestimates of differences in response to treatment. Provision of adequate buffers is most critical on small plots, because small plots have a greater proportion of edge to total area than do large plots.

A frequently quoted rule of thumb is that width of buffer should equal stand height (Fabricius and others 1936, USDA Forest Service 1935). In the tall stands of the Pacific Northwest, however, this rule often gives values that seem unreasonable and impractical in application. Buffer size is sometimes specified as a proportion of plot area, but any single fixed proportion will give unreasonable values when applied to extremes of plot size.

If future destructive sampling of individual trees in the buffer is anticipated, width of the buffer may need to be increased to allow for this and to insure that the sample trees can be considered representative of conditions on the measured plot proper.

An additional isolation strip outside the treated buffer may be needed if there is an adjacent drastically different stand condition (for example, a clearcut), an abrupt site change, or concern over possible movement of fertilizer.

**RECOMMENDATIONS:** A rule that is probably adequate for most situations, provided adjacent conditions are not drastically different, is that width of the buffer should be at least equal to the expected crown width of dominant trees at the end of the planned period of observation. The Forestry Commission (1979) recommendation of 33 feet (10 m) seems reasonable as a general guide.

## **Surveying and Marking Plots**

Much time is lost relocating inadequately monumented plots. Lost corners and carelessly surveyed plots are frequent sources of error in plot areas and in corresponding values of stand statistics.

The plot center or a plot corner should be referenced to some easily relocatable point along a road or other access route, by compass bearing and measured distances. Other plots in the installation should be referenced to this by bearings and distances, and a careful sketch map prepared adequate for relocation of the plots by someone unfamiliar with them. The map should include approximate location in relation to the public lands survey system.

Plot centers and corners must be marked by stakes of some permanent material, such as metal, or substantial stakes of preservative-treated wood. Stakes should be marked in a way that positively identifies the plot and the particular corner and should be witnessed by appropriate paint blazes or scribe marks on adjacent trees. Declination used should be recorded. Bearings and horizontal distances between corners or centers must be carefully measured and recorded. The sketch map should show all bearings and distances needed to relocate plot centers and corners.

Large plots, elaborate installations, or difficult terrain may warrant use of transit surveys, including computation of error of closure to a preassigned standard. Smaller plots and simpler situations can be adequately handled with staff compass and tape, provided care is used. To insure against blunders, boundaries should be run twice in opposite directions, or error of closure calculated. Errors should not exceed one-half degree in angles and 1:100 in horizontal distances, or 1 percent error of closure.

Plot borders should be marked with paint blazes or signs (except where public attention is undesirable) or standard scribe marks on adjacent trees facing the plot border. In dense stands they should be carefully delimited with string before the trees are initially tagged and measured.

A standard record form should be used and checked to insure that all specified items are recorded.

## **Plot Protection**

There must be an agreement with the organization administratively responsible for the area to protect the installation from disturbance for the planned period of observation. The land manager must be informed of the exact location and nature of research plots. Organizations should have a standard procedure for insuring that managers have an up-to-date record of research installations on their lands, and that these are not disrupted by forest operations without prior consultation and agreement with the research organization.

Common hazards include road construction, thinning operations, and aerial application of fertilizers or herbicides. Any of these can quickly destroy the usefulness of a research installation.

## **Plot Measurement**

All measurements and records on a given installation should be either in metric or in English units. The two should not be mixed. Tapes and instruments graduated in both systems invite errors and should be avoided where possible. In general, metric units are preferable for new installations. Measurement of old installations should continue in English units until the entire system of records is converted to metric.

## **Record of Initial Conditions**

General characteristics and past history of the site and stand, so far as these are known, should be recorded at the time of the initial measurement using a standard procedure and specifications. This includes such items as location (public land survey, map coordinates, political subdivision); ownership; administrative responsibility for the area; elevation; aspect; slope percent; stand origin (natural, planted, seeded, planted with natural fill-in); forest type; age at time of first measurement (even-aged stands); known past treatment or injury; estimated site index (specify system); soils classification and habitat type, when available. Quantitative items such as elevation, aspect, and age should be recorded as numerical values rather than classes, to provide flexibility in later use. For example, the practice of recording aspect as cardinal direction only—instead of azimuth—prevents use of the trigonometric functions in later analyses to describe the location of maximum and minimum growth.

There must be a complete record of stand conditions at the time of plot establishment and immediately before any treatment. All stems removed should be recorded by species and diameter at breast height (d.b.h.) and any treatment should be completely described. If d.b.h. is not directly available for cut trees, it should be estimated from measured stump diameters and stump heights (Alemdag and Honer 1973, Beck and others 1966, Chambers 1978, Curtis and Arney 1977, McClure 1968). When plots are established in stands which have had cutting prior to plot establishment, date of cut should be ascertained and the dimensions of trees removed from the plot should be estimated by stump measurements or otherwise.

Although diameters can be estimated from stump measurements with reasonable accuracy under favorable conditions, the procedure becomes unreliable when trees are small, if stumps are not recent, or if portions of the plot are covered with slash or brush or have been disturbed by logging equipment. Direct measurement before trees are cut is preferable.

## **Tree Numbering**

Each live tree of measurable size within the plot should be assigned a permanent identification number. This is necessary for later separation and summarization of the components of forest growth; namely, survivor growth, mortality, cut, and ingrowth (Beers 1962).

Live trees that are below minimum measurable size at the time of initial plot establishment but appear likely to grow to measurable size later may also be assigned numbers and tagged at the time of establishment, even though d.b.h. is not measured. Though initially time consuming, this insures that numbers will be in sequence—thereby simplifying relocation of trees and handling of record sheets at subsequent measurements. This practice is desirable in plantations and similar situations where the number of such stems is limited and most will later reach measurable size.

As an alternative procedure for insuring that ingrowth trees will be numbered in sequence with adjacent trees, tree numbers assigned at time of plot establishment can be multiples of 10. When an ingrowth tree is later found, it is then assigned the number of the nearest initially numbered tree, plus 1, 2 . . . 9 as the case may be. For example, if a tree was initially assigned the number 1120, numbers 1121 through 1129 are then available for subsequent assignment to nearby ingrowth trees. This system can be used when the number of very small trees makes initial tagging of all trees impractical.

The method used for numbering trees will depend in part on size and characteristics of the trees. Metal tags attached with aluminum nails at breast height (b.h.) are convenient for large thick-barked trees (nails should be driven no farther than necessary to stay in place, with the tag placed at the nailhead so that it does not quickly become overgrown). On small trees and thin-barked species, nails may cause swellings that interfere with measurement; where this is a problem, either tags can be attached at a lower or higher point (with b.h. a fixed distance from the nail, preferably indicated by a paint mark), or painted numbers can be used instead. For very small trees, tags can be wired to a branch near b.h. If nails are used, they must be pulled as needed at each measurement to prevent bark overgrowing the tags. Nails should be removed and the tag nailed to a root or below stump height before trees are cut. This prevents damage to saws and allows identification of cut trees.

If painted numbers are used, these will require repainting as needed at subsequent measurements to remain legible.

If tags are used when plots are established, the field crew should be provided with sets of tags prenumbered in sequence. They should also have a label maker and metal label tape to supply tags needed if the sequence provided is exceeded (duplication of tag numbers on the same plot *must* be avoided).

It is sometimes desirable to use a distinctive paint marking on site trees or height sample trees (discussed on p. 28). It is often convenient to divide the plot into strips or sectors with string to insure that no trees are missed and that tags are arranged in a systematic manner (fig. 5). For reasons discussed later, it may be desirable to divide the plot into numbered subplots so that trees can later be sorted by subplots when wanted. Relocation of trees during plot remeasurements will be facilitated if all numbers are placed on the same side of the trees, within strips or subdivisions of the plot, arranged so that tags face the direction of travel across the plot in a systematic sequence.

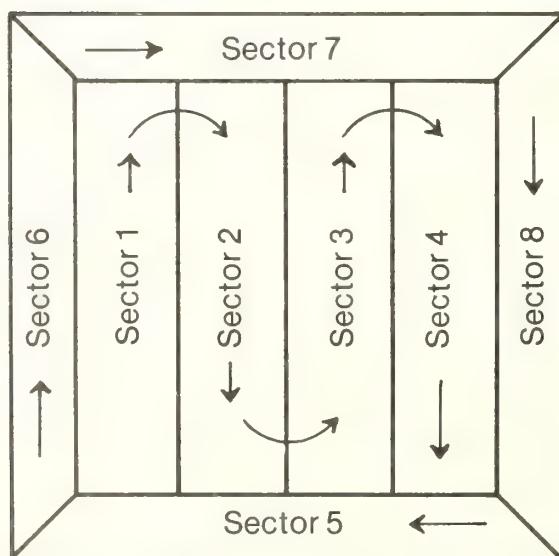


Figure 5.—Plot divided into sectors; arrows show sequence of tree tagging and measurement. Tags should be positioned to face direction of travel. Subdivision lines are best oriented in the direction most nearly parallel to the contour, to minimize effort in traveling between trees and to facilitate use of sectors in distributing site trees across any site gradient.

A consistent procedure should be used with "line trees" in determining whether or not to consider them on the plot and tag them. The decision is best based on location of the center of the tree at stump height. Trees exactly on line by this standard can be classified as "in" or "out" according to the direction of lean, if any. Borderline cases can be classified as "in" or "out" alternately or by coin toss. "Out" trees should be identified by paint blaze or standard scribe mark facing the plot, to prevent later confusion.

Depending on stand conditions and stage of development, dead limbs may be pruned to a height of 6 or 7 feet to facilitate numbering and later remeasurements.

At each remeasurement, a search should be made for additional unnumbered trees and new numbers assigned to any found. If this is neglected, impossibly large "ingrowth" trees will later appear in the record. Such impossible "ingrowth" introduces abrupt changes in calculated periodic growth values, and the missing values must then be supplied by borings or by estimating past unmeasured diameters of these trees.

Note that when tagging such new trees in the field, one should *not* transfer to them numbers previously used on trees that have died or been cut. This practice, though convenient in the field, causes endless confusion. A label maker should be carried and tags made as needed for newly assigned numbers. The number of the nearest previously numbered tree should be noted on the field sheet as an aid to later relocation.

## Determination of Breast Height

For consistency in successive d.b.h. measurements on the same tree, all measurements must be made at the same point on the tree bole. The system used *must* include a mark at the b.h. point on all numbered trees. This mark may be a painted band or the location of the tag nail. There are, however, some unresolved inconsistencies in definition of b.h. which require a choice.

In the United States, breast height has been defined both as 4.5 feet above mean ground level (common practice in many past research studies) and as 4.5 feet above ground level on the high side (common inventory practice). The former definition sometimes gives unreasonably low points for large trees on steep slopes; the latter definition gives a point that, for trees on steep slopes, rises as the tree increases in size (Bruce 1980). A further source of uncertainty is that in many cases the standard used in collecting the data used to construct existing volume tables is unknown.

On gentle slopes, the difference between the two procedures is slight.

A second inconsistency arises in the shift from English to metric measurements. Traditionally, b.h. has been defined in the United States as 4.5 feet above ground, however "ground" is defined. Some people in the United States and other English-speaking countries have used the equivalent metric value of 1.37 meters; however, the international standard is 1.3 meters and this will probably eventually become standard in the United States, as it is now in Canada (Bruce 1976, Demaerschalk and Kozak 1982).

**RECOMMENDATIONS:** When new plots are installed, it is best to establish and mark the b.h. point measured from ground level on the high side, thereby at least partially avoiding the unreasonable heights that sometimes arise from use of average ground level on steep slopes. All subsequent measurements should be made at this same marked point on the tree. In new studies, measured in metric units from the start, b.h. height should be the international standard 1.3 meters.

A consistent procedure should be used for forked trees and trees with abnormal swellings at the b.h. point. Suggested conventions are (fig. 6):

1. If a tree forks above b.h., treat it as a single tree, with the tag and diameter measurement below the swelling caused by the fork but as close to normal b.h. height as feasible.
2. If a tree forks below b.h., treat it as two trees, with the tag and diameter measurement located at (1) 2.0 feet (0.6 m) above fork at the initial measurement or (2) 4.5 feet (1.3 m) above ground, whichever is higher.
3. If the tree has an abnormal swelling at the normal b.h. point, tag and measure it immediately above the irregularity at the point where it ceases to affect stem form.

#### Determination of Stand Age

Stand age must be determined for all even-aged stands. This is best done at the time of first plot measurement.

Tree ages are normally determined by boring at b.h., by counting rings on stumps, or from known planting dates. Some estimate of intervening years is necessary to convert age to corresponding total age from seed. The record may show age as either total age from seed or age at b.h. but must clearly specify which and should indicate the basis for conversion from actual measurements to the ages given.

A stand age based on borings at b.h. is highly desirable in plantations as well as in natural stands, even though year of planting may be known. Time required to grow to the b.h. point varies with weather, site preparation, brush control, and other factors and is often considerably shorter in plantations than in natural stands. Hence, inconsistencies in method of determining age can introduce apparent differences among stands that have little meaning for long-term development. Use of measured age at b.h. in site estimation and growth relationships avoids at least part of this variation.

Stand age is meaningful only for even-aged stands. It should be defined as average age of dominant or crop trees or of trees selected by some nearly equivalent numerical rule, such as the 40 largest per acre (100/ha). Occasional large residuals, lower crown classes, and trees unlikely to reach rotation age should be excluded. The sample should normally include designated site trees, if any, plus additional trees selected from the stand tally on the basis of dominant or crop tree classification or the 40 largest trees per acre.

The sample should be large enough to determine the mean age of dominant (crop) trees on the plot to a prespecified standard of precision. Staebler (1954) suggests a standard error of the mean of 1.0 year or less, after elimination of obvious outliers.

Individual tree ages used in calculating the plot mean should be retained in the record, with identifying tree numbers. The plot age carried in the record should be the mean calculated to the nearest year, *not* a broad age class category.

In mixed species stands, sufficient samples of each major species should be taken to determine whether or not age differences exist among species.

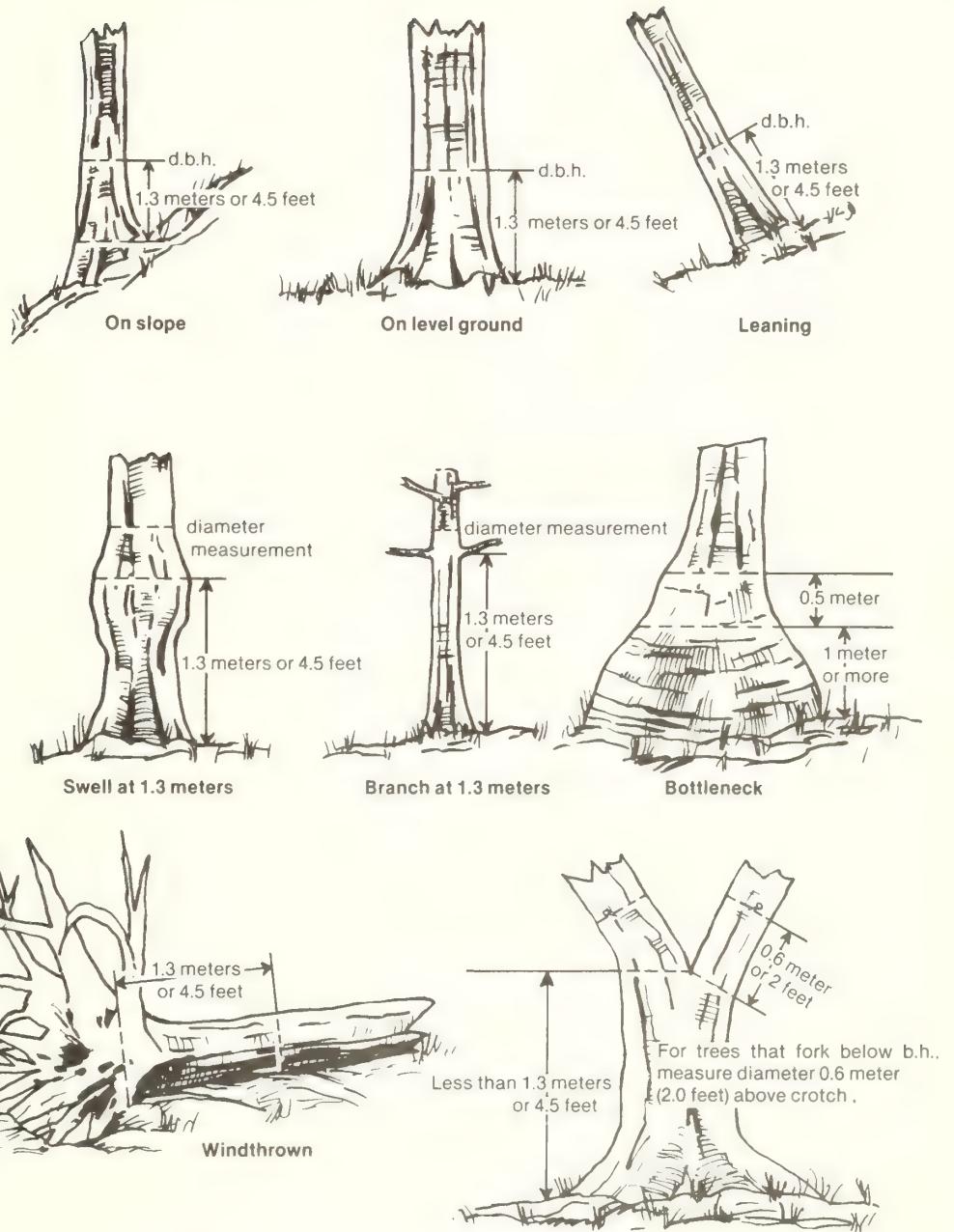


Figure 6.—Measuring diameter at breast height of trees in various situations.

## Tree Dimensions

Standard procedure at each scheduled plot measurement must provide for:

1. D.b.h. measurement of all trees above the lower limit of measurement.
2. Classification of measured stems by crown class, tree status, condition, cause of injury or death, in accordance with a standard coding system. This must recognize the categories:
  - a. Survivors.
  - b. Ingrowth.
  - c. Mortality.
  - d. Cut.
  - e. Intentionally killed trees.

Where variable radius plots are used, there will be the additional category "ongrowth". In even-aged stands, understory stems (those clearly of a younger age class than the main stand) should be recognized as a separate crown class.

3. Measurement of heights of a sample of trees sufficient to provide a reliable height-diameter curve and estimates of stand average height, top or dominant height, and site index. (Measurement of heights to live crown is a highly desirable addition.)
4. An estimate of tree form. This is most commonly made indirectly by means of standard volume tables or taper functions based on diameter and height but may be done by direct measurement of a sample of trees.

When plots are remeasured, it is advantageous to use a standard tally sheet (fig. 7) or recording device containing the previous measurements on each tree. New and old measurements should be checked for reasonable agreement, and major discrepancies checked by remeasurement of the tree. This will frequently avoid gross blunders and recording errors, which are easily corrected in the field but which become a major nuisance if not caught until the compilation stage.

The initial measurement is particularly prone to blunders and recording errors, since no check is available. One method of avoiding troublesome errors in the initial measurement is to make two successive measurements at the time of plot establishment, exchanging the measurement and tally roles among the crew. Measurements that do not agree within reasonable limits are repeated and corrected on the spot. The time required for such a second measurement, although considerable, is usually a relatively small fraction of the total time required for initial plot installation and measurement.

**Diameter measurements.**—D.b.h. of each tagged tree should be measured at the marked b.h. point at each plot remeasurement, normally to the nearest 0.1 inch or 1.0 millimeter. Except in stands with many very small stems, this is best done with a diameter tape.

When a tree that died since the last measurement is encountered, its diameter is recorded, together with a mortality code indicating that it was found dead at this measurement. It will save time in future remeasurements if such trees are blazed and the tag nails driven into the wood so that the tag does not fall off as the bark decays, making the trees easily identifiable as previously recorded mortality.

Figure 7.—Plot measurement record form.

It has been a common practice in the past to measure only trees above an arbitrary d.b.h. limit, more or less corresponding to some merchantability standard. This was usually done to simplify fieldwork, but it has been the source of numerous difficulties in analysis. Such truncation of diameters distorts the statistics of stand average diameter and number of trees, hampers or prevents fitting of diameter distribution functions, and often makes different data sets completely incompatible. It should be avoided.

In principle, it is desirable to tally all stems taller than b.h.; however, very small stems are difficult to tag and measure and may be numerous. As a practical matter, it is usually necessary to adopt some lower limit of measurement such as 0.5 inch or 1.5 inches or 2.5 centimeters. Higher limits should *not* be used. Where it is not feasible to measure all trees on the plot above such a limit, a subsampling scheme can be adopted.

When fixed area plots are established in very young stands and are to be observed over an extended time period, a plot size adequate for the initial condition is much too small for the stand condition expected at the end of the observation period. Conversely, a plot size suitable for the final stand condition may initially involve tagging and measuring a prohibitive number of small stems.

A procedure sometimes used in this situation is to tag and measure all stems on subplots within the main plot, but only stems over a specified larger d.b.h. (no larger than absolutely necessary) on the remainder of the plot. The sample of small trees must be large enough to provide stable estimates and must be representative of trees on the main plot area. Since small stems are frequently clumped, several systematically located subplots within the main plot may be preferable to the single concentric plot often used. A common mistake is insufficient sampling of the small stems. Particular care must be taken that the ingrowth over the larger d.b.h. limit is tagged, numbered, and measured at each remeasurement.

Note that increment values for each successive period will be based on a slightly different tree sample (because of ingrowth into the main plot), that this design complicates computation of plot summaries, and that it involves a continuing need to search for and tag numerous new ingrowth stems at each subsequent measurement. Therefore, such subsampling should be used only when absolutely necessary.

When variable radius plot (point) sampling is used, the tree population must be subdivided by a limiting d.b.h., below which trees are recorded on a circular fixed area plot and above which trees are recorded if their diameter subtends an angle larger than the critical angle for the basal area factor selected for the larger trees. Size of the fixed area plot for small trees should match the size of the variable radius plot at the limiting d.b.h. A suitable choice of limiting d.b.h. and associated size of the fixed area plot can reduce the problem of measuring very large numbers of small trees, while including enough such trees to define the diameter distribution.

**Height measurements.**—Stand height is (with age, number of trees, and average diameter) one of the basic descriptors of a stand. It is essential to most analyses of growth and yield. Heights are necessary for computation of volume and volume increment, for estimation of site index, and for characterization of stand conditions and stand development. Because measurement of heights is time consuming and frequently inaccurate, height sampling and measurement are the weakest points in much existing data.

For species in which the limit of merchantability is generally determined by bole diameter, as in most conifers, only total height need be measured. Merchantable heights, if wanted, are better determined from taper curves. In species where the limit of merchantability is frequently determined by "breakup" of the main stem rather than by diameter (for example, many hardwoods), it may be desirable to measure merchantable height in addition to (but not instead of) total height.

In most situations, it is impractical to measure heights of all trees on the plot, and one must resort to subsampling. A suitable sample of trees should be measured for heights when the plot is established and at each remeasurement.<sup>4</sup> This requires (1) adequate sample size, (2) efficient distribution of the sample, and (3) careful height measurement. Measurement of only a few heights at a given date, insufficient for construction of a height-diameter or volume-diameter curve, serves no useful purpose.

#### RECOMMENDATIONS:

1. Each plot or cluster of subplots should be sampled independently. Samples generally cannot be combined across plots without biasing analyses.
2. Height sample trees are best drawn initially from the plot tally, rather than selected visually. After the initial sample is drawn, trees with broken tops, pronounced lean (over 10°), severe malformations, or disease should be rejected. Sample trees should be reasonably well distributed across the plot area.
3. The sample should include trees from the full range of diameters present. A common and serious mistake is omission of small d.b.h. classes, which leaves the curve shape undefined; the sample should not be confined to only dominants and codominants.
4. Large d.b.h. classes should be sampled more heavily than small d.b.h. classes, since they contribute more to volume, volume growth, and value.
5. When designated site trees are used (discussed on p. 34), these should routinely be included in the height sample, with additional sample trees selected as needed to provide a satisfactory distribution across the range of diameters.

<sup>4</sup> Given several well-distributed height samples, satisfactory curves for intermediate dates can often be obtained by interpolation or by fitting a system of height-diameter-age curves (Curtis 1967a). This, however, is computationally bothersome, may obscure real differences in growth among periods, and is usually a makeshift solution made necessary by past omissions. It is better to avoid the need.

6. Normally, except where new trees are needed replace trees lost by cutting, mortality, or severe top breakage, the same height sample trees should be used at each successive measurement. This provides better estimates of height increment than independent sampling at each measurement (even though it may perpetuate peculiarities of the initial sample). It may be convenient to mark trees with paint for easy subsequent recognition. Lost trees should be replaced by other trees of similar diameter and crown position. Over long periods or in plots established at an early stage of stand development, it will become necessary to delete some trees and add others to maintain a satisfactory distribution across the range of diameters.

A rule of thumb used at the Forestry Sciences Laboratory in Olympia, Washington, calls for height measurement of at least 15 trees per plot, with two-thirds distributed across the d.b.h. classes larger than average stand d.b.h., and one-third distributed across the smaller d.b.h. classes. This is a *minimum* applicable to relatively small homogeneous plots of a single species with well-established crown differentiation. More trees will be required in large plots and mixed species stands and in young plantations where crown differentiation is only beginning.

Height estimates should be compared with previous measurements before the field crew leaves the plot. If obvious discrepancies are found, the measurement should be repeated to determine whether the present or previous measurement is in error. Where conditions allow, height growth since the previous measurement can also be estimated from internodal distance, as a check in doubtful cases.

If more than one species are present, a decision must be made on sampling the associated species. Options are:

1. If the secondary species represents a minor component of the plot, and particularly if it is not greatly different in characteristics from the primary species, then the simplest course may be to ignore height differences and sample the primary species only—accepting any error in volume computations that arises from use of heights of the primary species in computing volumes for the secondary species.
2. If the secondary species is small in numbers but includes a few large trees with a substantial contribution to plot volume, the best course will be to measure heights of all such trees and use these heights in computation of their volumes.
3. If the secondary species represents a substantial portion of both plot volume and numbers of trees, then a height sample should be drawn and measured the same as for the primary species.

Choice of instruments and procedures for measurement of heights is influenced by expected tree size, terrain, and brush and understory conditions.

In young stands height poles are fast and accurate. Commercially available telescoping poles provide measurements to 30-45 feet in height, depending on the model. Certain sectional poles can be used, with difficulty, for heights up to 50-60 feet or more. Care must be taken that the pole is kept close to the tree and that the pole tip is at the same distance from the observer as the tree bole. The observer should stand as far away as possible.

The most common procedure has been to measure slope distance from observer to the tree with tape, and angles to tip and base of tree with an Abney level or similar instrument graduated in percent slope. Then (1) calculate corresponding horizontal distance using slope correction factors given in table 4 in the appendix (= cosine of angle in degrees), and (2) calculate tree height as:

$$H = (\text{horizontal distance}) (\text{slope percent, tip}) \\ - (\text{horizontal distance}) (\text{slope percent, base});$$

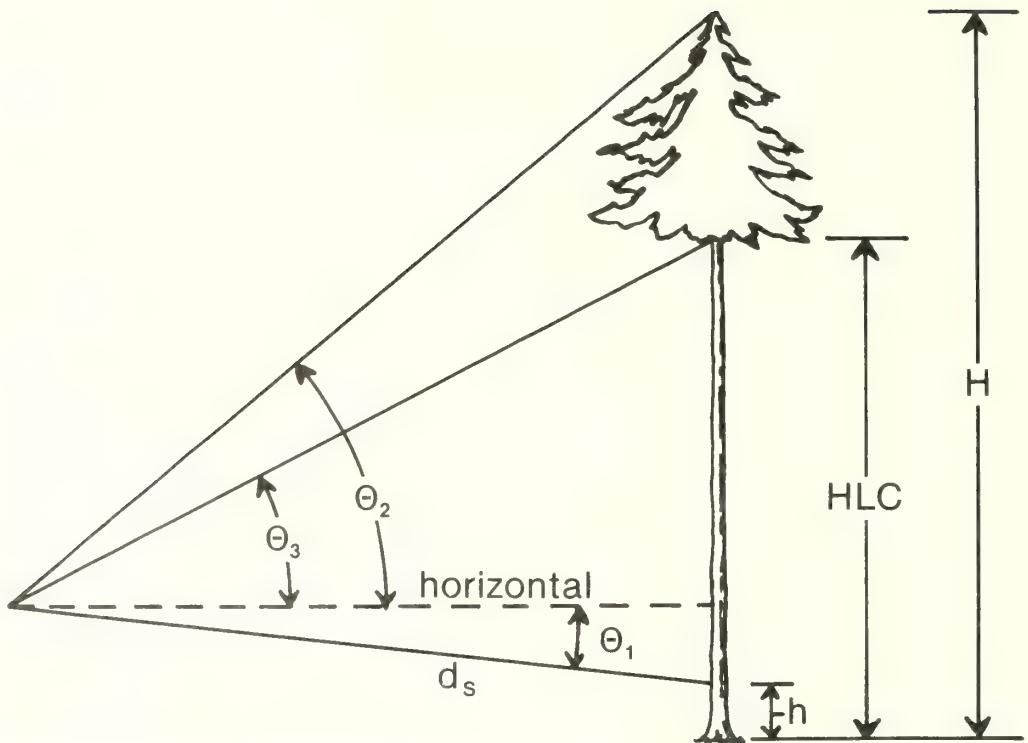
where, slope to base is negative if below horizontal, positive if above.

This procedure is adequate for moderate size trees on moderate slopes, without heavy brush. Special circular slide rules (Haig 1925, Stage 1959) simplify field computation of heights, but these are being replaced by the programmable pocket calculator. With such a calculator and a clinometer graduated in degrees, cumbersome tables and calculation of horizontal distance as a separate step can be eliminated, using the procedure shown in figure 8. Angles should be read to the nearest one-fourth degree (or 1 percent).

It is often convenient to adopt a standard procedure of sighting on the b.h. mark rather than the base of the tree (often obscured by brush), and then adding the value of b.h. (4.5 ft or 1.3 m) to the calculated height. A flashlight is useful to provide a sighting point in heavy brush or shade.

On steep terrain or if heavy brush is present, distance measurement by tape becomes laborious and inaccurate, resulting in poor height measurements. Procedures not requiring tape measurement of distance are advantageous.

Several optical rangefinders are on the market. In general, the simpler types lack the precision needed for research work. Some limit the user to a fixed distance, which is impractical in dense stands where trees are often visible from only a few points. The more precise instruments are expensive, and some are cumbersome and difficult to use with poor lighting and visibility.



### Formulas (alternate forms):

$$(1) \quad H = d_s * \cos \Theta_1 * (\tan \Theta_2 - \tan \Theta_1) + h;$$

$$(2) \quad H = d_s * \frac{\sin(\Theta_2 - \Theta_1)}{\sin(90^\circ - \Theta_2)} + h;$$

(3)  $d = d_s * \cos \Theta_1$ , and

$$H = d * \frac{(\text{slope } \Theta_2 - \text{slope } \Theta_1)}{100} + h;$$

since slope  $\Theta$  in percent =  $\tan \Theta * 100$ .

Figure 8.—Estimation of tree height using clinometer and tape measurement of slope distance.

$\Theta$  is angle in degrees.

H is total tree height.

HLC is height to live crown.

h is height to lower aim point (usually, b.h.).

$d_s$  is slope distance, measured parallel to line of sight from observer to center of tree at lower aim point.

Angles should be measured to nearest one-fourth degree or 1 percent. Formulas for HLC are as shown, but with  $\Theta_3$  replacing  $\Theta_2$ .

A useful procedure, requiring only a height pole and a clinometer, which provides satisfactory precision for moderate size trees while eliminating tape measurement of distance, is illustrated in figure 9 (Curtis and Bruce 1968, Bell and Gourley 1980).

Tall trees (over 100 feet or 30 meters) tax the accuracy of the Abney level and similar instruments. Sighting angles over 45° should be avoided. Precision of hand-held instruments can often be improved by resting the instrument hand on a staff as support. This reduces hand tremor and provides a constant instrument height for all angles measured from a given point. It is often advisable to make two height estimates from different positions and average the results, since errors are the combined result of errors in clinometer reading and in measurement of distance, and of any lean in the tree. An alternative procedure, sometimes useful in improving height growth estimates in relatively open stands in which the tree tip is easily visible, is to record bearing and slope distance from tree to observer at the initial measurement and then take subsequent height measurements from the same position.

A tripod-mounted optical instrument such as the Bitterlich Telerelaskop or the British "Enbeenco" clinometer will improve accuracy.<sup>5</sup> Special studies requiring accurate height values for individual trees require measurement of angles by transit. For tall trees in stands with reasonable visibility at rod height, the transit with stadia measurement of distances may be not only the most accurate method but also relatively rapid.

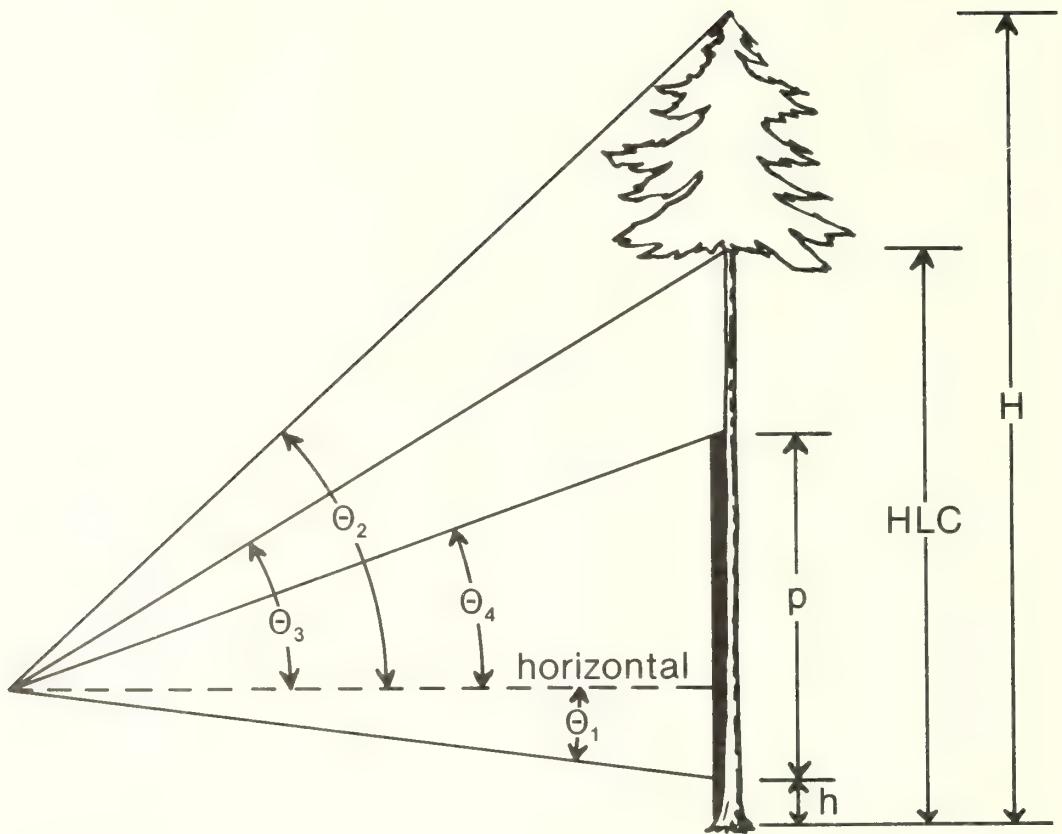
**Crown measurements.**—Crown dimensions have only rarely been measured in the past. Yet, crown development reflects the past history of trees and stands and is related to competitive status and growth rate and to future growth potential.

Live crown length is the most easily determined crown dimension. It is associated with tree competitive status and potential response to treatment and has been a useful predictor of growth in recent yield research (Hahn and Leary 1979, Holdaway and others 1979, Krumland and Wensel 1980, Stage 1973). In combination with total height, live crown length is equivalent to height to live crown or live crown ratio. These can be obtained by including measurement of height to live crown for the trees in the height sample.

Some care is needed in defining base of live crown for consistency among different installations and measurements made by different individuals. A suggested definition is "lowest whorl with live branches in at least three quadrants, exclusive of epicormic branches and whorls not continuous with the main crown." Irregular and one-sided crowns must be ocularly "adjusted" to estimate the corresponding position of the base of a normally formed crown of the same volume.

Crown widths are also frequently of interest in studies of tree and stand growth and response to treatment.

<sup>5</sup> The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.



### Formulas:

$$H = \frac{p * (\tan \Theta_2 - \tan \Theta_1)}{(\tan \Theta_4 - \tan \Theta_1)} + h;$$

$$HLC = \frac{p * (\tan \Theta_3 - \tan \Theta_1)}{(\tan \Theta_4 - \tan \Theta_1)} + h.$$

Figure 9.—Estimation of tree height by the pole and clinometer method.  $\Theta_i$  is angle, in either degrees or percent. Since  $\tan \Theta = 0.01 * \text{slope } \Theta$  in percent, and the factor 0.01 cancels, the computational formulas are the same for either unit.

H is total tree height.

HLC is height to base of live crown.

h is height of lower aim point (usually b.h.).

p is length of portion of pole above lower aim point. Length of pole should be at least one-fourth of total tree height, more when feasible.

Care must be taken that base and tip of pole are against the tree bole, or beside the tree at the same distance from the observer as the tree bole.

Measurements should be taken perpendicular to direction of any tree lean.

Under favorable conditions, crown widths can be measured on large-scale aerial photographs. Ground measurements require vertical projection of crown margins and can be made with such simple instruments as the Suunto clinometer, or with any of a variety of instruments constructed especially for the purpose (Montana and Ezcurra 1980, Shepperd 1973).

Ground measurements of crown width are easily obtained for short trees with crowns extending nearly to the ground but become difficult and inaccurate with increasing height to live crown, particularly when crowns are in contact with adjacent trees. Ground measurement of crown widths is considerably more difficult and time consuming than measurement of height to live crown.

**RECOMMENDATIONS:** Height to live crown should be measured on new research installations and at least some of the more valuable older installations.

Crown width should be measured only on selected installations where there is a clear and specific purpose for such measurements.

**Upper-stem diameters and tree form measurements.**—There may be need to measure upper stem diameters on a sample of trees for either of two reasons:

1. The form estimate implicit in conventional double-entry volume equations may not adequately account for a change after treatment; hence, estimates may be needed for individual plots or treatments.
2. Information on stem taper and size assortments may be needed as a basis for subdivision of tree and stand volume into size, product, or value classes.

The question of possible effects of stand treatment on standard volume equation and taper function estimates has not been entirely resolved. Direct estimation of individual tree and plot volumes is laborious and expensive. Most researchers have preferred—in the absence of clear evidence that individual plot volume and taper equations are needed—to assume that treatment effects on form beyond those incorporated in standard volume equations can be ignored; hence, that upper stem measurements specifically for this purpose are probably not needed. This is assumption rather than clearly demonstrated fact.

There is generally a need for estimates of volume to different merchantability limits, and by size, product, or value classes. Some information is easily obtainable from the tarif system (Brackett 1973, Turnbull and others 1980); more complete information is given by stem taper curves.

Suitable taper curves are often available from other sources. If not, it may be desirable to include upper stem measurements on a sample of trees to provide the basis for developing such curves and associated assortment tables. Needs for such information and existing sources should be considered as part of the study planning process.

If there is need for upper stem measurements, these can be obtained either by measurement of felled trees on the plot or on the adjacent buffer strip, or by dendrometry. Commercially produced instruments suitable for measuring upper stem diameters in the standing tree include the Barr & Stroud dendrometer, the Wheeler penta prism caliper (Wheeler 1962), the Bitterlich Telerelaskop, and the transit dendrometer (Robinson 1962).

Required measurements are stump height; stump diameter; d.b.h.; diameters outside bark at height intervals of 0.05, 0.10, 0.20...1.0 fractions of total height (or more or less equivalent absolute height intervals); bark thickness at point of diameter measurement; total height; and merchantable height, in species where this is determined by factors other than diameter. Height to base of live crown is a desirable additional measurement. Detailed procedures and various taper and volume equations are given by Bennett and Swindel (1972), Bitterlich (1981), Bruce (1972), Bruce and others (1968), Cao and others (1980), Demaerschalk and Kozak (1977), Grosenbaugh (1963), Gray (1956), Kozak and others (1969), Martin (1981), Max and Burkhart (1979), and Ormerod (1973).

The time and cost of such data collection and analyses are substantial and should be carefully evaluated in relation to needs before such work is undertaken.

## Site Index Estimates

Even-aged stands are commonly classified by site index, the expected height of a specified portion of the stand at a specified reference age, as an index of productivity. Details of definition of the stand component used and the estimation techniques differ among species and regions because of the evolution of techniques over time and the vagaries of different authors. Normally, classification is based on the principal species present, although approximate conversions are possible for species having similar site requirements.

Established procedures often involve subjective choice of site trees on the basis of crown class or other descriptive criteria. Newer procedures define site trees by position within the diameter frequency distribution. Where a procedure is well established, plot measurement procedures should provide for its use. Procedures continue to evolve, however, and a procedure in general use at the start of an experiment is not necessarily that which will be used at its conclusion.

Trees with damage affecting height and height growth should be excluded. Height estimates for the specified stand component may be obtained as values read from the height-diameter curve for the mean diameter of the specified component, or as a mean of measured heights of sample trees drawn from that component. If the latter procedure is followed, guidelines will be needed for the required number of sample trees, based on the variability of site index estimates. In general, the required number will increase as plot size increases and also as the difference between plot age and index age increases, but the number cannot exceed the number of qualifying trees present on the plot and, if necessary, its buffer strip. A site index estimate should not be based on fewer than four trees per plot, and more are desirable when allowed by plot size and component specifications. Site trees should be identified on the plot record and remeasured at successive plot remeasurements as long as they remain qualified site trees. Age of all site trees should be determined by boring at b.h.

Site index estimates will improve as stand age approaches the reference age. Therefore, a new estimate should be made for each measurement date. Actual shape of the height growth curve varies among stands. As young stands develop, later estimates of site index will more accurately represent the growth potential of the site. Site index estimates often change over time, and the record should be updated as this occurs.

**RECOMMENDATIONS:** In general, it is best to base site index estimates on a stand component defined in terms of the d.b.h. frequency distribution rather than subjective crown classes. The preferred basis is a specified number of the largest diameter stems per unit area (Curtis and others 1974), such as the 40 largest per acre (100 largest per hectare).

Application of any selection rule should include a “well-distributed stems” requirement to insure that the average represents the entire plot area and is not materially influenced by any site gradient across the plot. (For example, on steep slopes the tallest trees are often found along the lower edge of the plot.) One means of insuring this is to divide the plot into subplots or strips parallel to the contour and of approximately equal area, and then apply the site tree selection rule separately within each subplot.

## Stem Maps

Consideration should be given to stem mapping selected installations expected to be major sources of long-term growth data. Stem maps can provide:

1. Easy relocation of missing trees and of sample trees drawn from the plot record.
2. Description of spatial distribution of stems.
3. Description of spatial distribution of mortality and injury.
4. Information needed for development of distance-dependent simulation models, which use measures of intertree competition based on individual tree dimensions and distances.

Stem mapping can be done rapidly in stands with moderate numbers of stems, good visibility, and easy terrain. It becomes laborious, expensive, and error prone when there are large numbers of small stems, difficult terrain, or dense brush; it should not be undertaken lightly under such conditions.

One procedure determines coordinates by reference to two tapes stretched at right angles, using right-angle prisms. Other procedures use angles and distances from plot center (best for circular plots) or aerial photography (open stands).

Stem mapping need be done only once on an installation. Once coordinates for each tree are available, actual stem maps for the first or any subsequent measurement can be produced by computer.

## Photographs

A sequence of photographs showing stand development over time is useful for both oral presentation of research results and illustration of publications. The need for photographs should be considered and procedures specified at the time a study is established. Usually, a sequence of photographs beginning with the initial plot measurement date should be obtained for at least a sample of plots, sufficient to illustrate the stand conditions and treatments involved.

Photos are most useful when they show the same scene at successive points in time. So far as is feasible with changing stand conditions, photos should be taken in the same direction from the same points at successive dates. Photo points can be identified either by distinctively marked stakes or by distance and bearing from plot corners or plot center. A person or some object of easily recognized dimensions should be included in photos to provide a size scale meaningful to the viewer.

For oral presentations, 35 mm transparencies are most useful, but they are generally unsatisfactory for reproduction; black and white photographs in larger film sizes (for example, 4 by 5 inches) are preferred for publication.

Photos are worthless unless they are carefully and completely identified by study, installation, plot, location, direction, date, photographer, and any special points illustrated. A systematic procedure must be used for identifying and filing photographs to insure that the needed information is recorded; that each photo can be associated with other records for a particular study, installation, and plot; and that negatives and transparencies are protected from damage.

#### Remeasurement Schedule

A plot remeasurement schedule should be specified and adhered to as closely as possible. A standard planning procedure should be provided to insure that scheduled remeasurements are not missed.

The interval between measurements depends on stand conditions and on the purpose of the installation. In general, measurements at relatively short intervals are needed for rapidly growing stands (young stands, good sites) or where there is major interest in short-term changes in growth in response to treatment. Longer intervals suffice in slower growing stands. Except where there is a specific need for measurements at short intervals to define the shape of a response function, measurements at very short intervals (say, under 3 years) are not generally useful because of the irregularities introduced by year-to-year variations in growth and the measurement errors involved in attempting to measure small changes.<sup>6</sup> With longer intervals and slower growing stands, limited deviations from the planned measurement schedule may be allowable, depending on the nature of the study; but measurements must not be missed or postponed when an associated treatment is applied. A complete stand measurement should be made whenever a thinning, fertilization, or other stand treatment is applied.

Research studies generally use a fixed interval for all plots in a given installation or study. This is usually specified in calendar years but may be defined by amount of height growth or other measure of stand development, as a means of allowing for differences from expected growth rates and obtaining closer comparability among installations.

Measurements should be made during the dormant season if possible. Although fractional years arising from measurement during the growing season can be used in analyses, they are a complication and a source of errors, which may be large for short growth periods. Changes in bole moisture content and the attendant shrinkage and swelling have measurable effects on diameters and estimated diameter increments; to a considerable degree, these effects are associated with season and are reduced by dormant season measurement.

#### Control of Treatments

**Thinning.**—Type, severity, and frequency of thinning in silvicultural research studies are normally specified in the study plan. Procedures for applying and controlling thinning on the ground to meet these specifications and needs for prethinning information will vary with study objectives and the required degree of control over the thinning operations.

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<sup>6</sup> A first remeasurement soon after establishment will, however, serve to correct measurement and recording errors made at the time of establishment.

In precommercial thinning, the objective is generally some specified number of well-spaced best trees, compatible with some target diameter for first commercial thinning. Detailed knowledge of present stand statistics is usually not necessary to apply the initial thinning, although knowledge of initial stand statistics may be needed in later analyses. For subsequent thinnings, knowledge of pretreatment stand statistics and growth may or may not be necessary to carry out the thinning, depending on study objectives and specifications.

In stands that have been previously spaced, the objective may also be to leave a specified number of well-spaced best trees. This can often be achieved without prior knowledge of stand statistics and growth. In some studies, however, knowledge of individual tree growth obtained by measurement may be the primary basis for deciding which trees to remove.

If study specifications call for retention or removal of some specified fraction of growth or growing stock, then the stand must be remeasured and stand statistics calculated before the marking is done, since the approximate volume and size distribution of trees are necessary as a guide to the marking operation.

The close control of residual numbers, size, and spatial distribution of trees needed in many silvicultural studies often requires subdivision of the plot and plot record into subplots or other subdivisions for marking purposes. Where very close control of residual spacing is wanted, the area may be gridded with string or otherwise at the desired spacing and the nearest suitable tree to each grid point designated as a leave tree. More commonly, it will suffice if the required number of reasonably well-spaced best trees is left on each subplot or other subdivision of the plot.

**Fertilization.**—Although operational forest fertilization is generally done by aerial application, most research studies use carefully controlled hand application. The plot is subdivided with string or paint into relatively small segments or squares, and measured amounts of fertilizer are applied to each subdivision. Although this uniformity of application is not consistent with the variability encountered in operational fertilization, it is necessary if the objective is to relate growth response to fertilizer dosage.

Plots are sometimes installed in operationally fertilized areas for monitoring purposes, in an attempt to estimate the gain in yield from fertilization. For meaningful results, one or both of two procedures must be followed: (1) the fertilizer dosage actually reaching each plot must be estimated by sampling with an adequate number of fertilizer traps on each plot or (2) clustered subplots may be distributed within portions of the treated area which are comparable in other respects, in a manner that insures that the average amount of fertilizer received by the cluster will approximate the nominal area dosage.

The gain in yield from fertilization is estimated by comparing growth on the fertilized plots with that on comparable unfertilized plots, or with some other estimate of expected untreated growth. Because of the relatively large treatment areas necessary with aerial application, it is difficult to provide comparable control plots and adequate replication. This fact, plus the high variability in actual dosage and in stand conditions within operational areas, makes direct quantitative measurement of treatment response difficult, inaccurate, and often impossible; hence the researcher's preference for uniform ground application in fertilizer studies (Bruce 1977).

## **Timing of Measurements in Relation to Treatment**

**Main plot.**—A complete stand measurement is needed whenever a thinning or fertilization treatment is applied to an installation. For plots that are fertilized only, a single measurement suffices. For plots that are thinned, information is needed for the live stand before thinning and after thinning, for trees cut, and for damage occurring during the thinning operation. Prethinning statistics may or may not be used as a basis for controlling the thinning operation, but they are always needed in analyses to describe the initial conditions. Associated control plots are rarely sufficiently comparable to provide satisfactory information. Postthinning stump measurements, though possible, are often inaccurate and are an undesirable substitute for adequate prethinning measurements.

When possible, the prethinning measurement and the actual thinning should be done during the same dormant season. Diameters of all trees should be measured before thinning. A postthinning check is then made to identify trees cut, destroyed, or damaged during the thinning operation. If there is substantial delay—one or more growing seasons—between initial measurement and the actual thinning, a complete remeasurement of the installation is necessary after thinning; this situation should be avoided.

When thinning is done at the time of plot establishment, alternative procedures may be used, depending on stand conditions and the expected numbers of cut and leave trees:

1. Permanently number all trees at the start.

Tag or paint all trees with tree number and a clear identification of the height at which d.b.h. is to be measured. Measure all trees for exact d.b.h. (nearest 0.1 inch or 0.1 cm). Then make a postthinning check to identify trees that were cut, destroyed, or damaged.

2. Temporarily tag all trees.

To avoid permanent tagging of trees that are measured only once and then cut, temporary numbered cards can be stapled to the trees. Numbers should be in the sequence in which trees are encountered and positioned so that the top edge of the tag denotes the height at measurement. Measure all trees and make the postthinning check as in (1). Permanently number the leave trees with tags or paint at the time of the postthinning check.

3. Preidentify leave trees.

If leave trees can be identified before measurements are made, it may suffice to measure and record other (cut) trees by 1-inch or 2-cm classes only.

- a. If numbers are assigned to these trees, they can be recorded in the order encountered which provides an indication of spatial position.

- b. An alternative, sometimes necessary when large numbers of small trees are cut, is a dot tally only of trees to be cut by size classes.

In either (a) or (b), all designated leave trees must be measured to 0.1 inch or 0.1 cm, numbered, and tagged or painted. The postthinning check is made as in (1).

4. Preliminary dot tally to guide treatment.

If pretreatment stand statistics are needed to guide treatment and methods (1) or (2) are not feasible, a dot tally of all trees by size classes may provide all that is needed. Leave trees are then marked, numbered, and measured before thinning. A postthinning check is made as in the other methods. (Numbering and accurate measurement of the leave trees can be deferred until the postthinning check but may be severely hampered by slash, and there is no opportunity to correct errors.)

When thinning is done at the time of plot establishment, it may be desirable to measure heights at the time of the postthinning check, rather than at the prethinning measurement. This avoids one-time height measurements on trees that are then immediately cut, and confines the sample to trees likely to be present at the next measurement. If, however, prethinning heights or volumes are needed as a basis for controlling treatment, heights must be measured before thinning. Substitutes for any trees cut can be remeasured at the postthinning check, which is often not made until the next growing season. In such cases, recorded height should be the height at the end of the previous growing season.

On previously measured plots, trees having prior height measurements should be remeasured at the time of the prethinning measurement. If any of these trees are cut or if additional trees are needed to maintain a desirable distribution of the height sample, the additional trees should be added at the time of the postthinning check. Growth estimates for the subsequent period can then be based on the same sample trees.

**Buffer strip.**—Although all residual trees on the main plot must be assigned permanent numbers, tagged, and measured at the time of plot establishment, the procedure to be followed with trees on the buffer strip may vary with the nature of the study and the treatments applied.

There is normally no need to tag or measure trees on the buffer strip surrounding an untreated control plot or any plot that is not thinned. There may or may not be need to measure buffer strip trees on plots to be thinned, as a basis for controlling thinning. If needed, a dot tally by diameter classes usually suffices.

Studies of individual tree competition that require information on diameter and location of competing trees may require numbering, measurement, and stem mapping of trees in the buffer strip, in the same manner as on the main plot. This situation arises when very small plots are used for such studies, in which it is not possible to designate a central subplot that is not influenced by trees in the buffer strip.

## Data Management

In many instances plot procedures, measurement standards, data recording codes and formats, and computational procedures have been developed more or less independently for each study by the individual or organizational unit concerned. These have been shaped by the investigator's immediate interests, experience, and limitations, and are often inadequately documented.

There is an urgent need to draw together accumulated data from different sources, to develop generally applicable estimates of treatment responses and potential yields. There is also a need to secure new data to supplement those now existing and to extend work to other species little studied as yet. The magnitude and costs of the plot establishment, plot measurement, and data management tasks lead to the conclusion that cooperative efforts involving several organizations are necessary. Cooperation and exchange of data are severely hampered by the general absence of uniform procedures for collecting, coding, recording, and summarizing data.

It is often a major task merely to discover what information exists. Much information is lost in attempting to reconcile inconsistent measurements and coding systems. Individual data sets frequently require their own tailor-made computer programs. Conversion to a common format and codes, essential for analysis by a single set of programs, is costly and prone to error.

Standardization is clearly needed. It is probably impractical to write detailed specifications for nationwide use. Research workers and cooperating organizations concerned with particular species or types of major importance should jointly prepare and adopt specifications for collecting and recording permanent plot data. These should provide for a minimum set of required measurements and information codes and a common basic record format.

The elements involved are:

1. Establishment and maintenance of an index of plot data relevant to specified objectives which can be continuously updated. This would provide specified information on the nature of the installation and treatment and status of existing data.
2. Agreement on and specifications for the basic design standards and measurements to be made on all permanent plots.
3. Adoption of a standard data format and coding system. It is impossible to anticipate the special interests and objectives of individual studies and investigators, and these should therefore be designed so that the user has latitude to subdivide codes or add additional special purpose codes, while retaining certain mandatory lower category codes common to all data in the system and necessary for compatibility with the associated computational package.
4. A package of computer programs designed to operate on data in the standard format and codes. These should include programs for:
  - a. Maintaining and updating index information describing plot status.
  - b. Editing and correcting plot and tree data.
  - c. Updating plot and tree records.
  - d. Calculating standard summaries of plot and tree data.

Portions of such systems already exist in some organizations, although most either are not publicly available or are incomplete or inadequately documented.

Western Forestry and Conservation Association (1977) gave a list of recommended items to be included in plot records. Arney and Curtis (1977) gave specifications for a plot index system and a detailed tree record format and coding system used in a large regional yield study in Douglas-fir. These codes and formats are being revised at the Forestry Sciences Laboratory, Olympia, Washington, and an associated package of computer programs is in preparation.<sup>7</sup>

This system is now in trial use in one large study in coastal Douglas-fir in Oregon and another in the hemlock-spruce type in Alaska. In its present form, the system is applicable only to fixed-area plots. Current expectations are that the specifications, programs, and documentation will be available by 1984.

Some examples of codes and types of information are given in "PDMS Tree Classification Codes" in the appendix. These are subject to change, and there is no implication intended that others should adopt these as given. They do, however, illustrate the types of information that must be provided in such a system.

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<sup>7</sup> Curtis, Robert O.; Clendenen, Gary W. Plot data management system (PDMS). Study plan on file at the Forestry Sciences Laboratory, Olympia, Washington. 1981.

## Literature Cited

- Alemdag, I. S.; Honer, T. G. Relationships between breast-height and stump diameters for eleven tree species from eastern and central Canada. Inf. Rep. FMR-X-49. Ottawa, ON: Forest Management Institute, Canadian Forestry Service, Department of the Environment; 1973. 14 p. plus tables.
- Arney, James D.; Curtis, Robert O. Code legend for standardized permanent plot records. In: Reimer, D. R., chairman. Standards of measure and data sharing: report of the Committee of Standards of Measure and Data Sharing (COSMADS). Portland, OR: Western Forestry and Conservation Association; 1977. 18 p.
- Beck, James A., Jr.; Teeguarden, Dennis E.; Hall, Dale O. Stump diameter-d.b.h. relationships for young-growth mixed conifer species. Calif. For. and For. Prod. 44. Berkeley, CA: University of California, School of Forestry; 1966. 6 p.
- Beers, Thomas W. Components of forest growth. J. For. 60(4): 245-248; 1962.
- Bell, John F.; Gourley, Robert. Assessing the accuracy of a sectional pole, Haga altimeter, and alti-level for determining total height of young coniferous stands. South. J. Appl. For. 4(3): 136-138; 1980.
- Bennett, F. A.; Swindel, B. F. Taper curves for planted slash pine. Res. Note SE-179. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1972. 4 p.
- Bitterlich, Walter. Telerelaskop techniques. In: Proceedings 17th world congress of the International Union of Forestry Research Organizations, Div. 4; [Date of meeting unknown]; Japan. [Place of publication unknown]: [Publisher name unknown]; 1981: 155-162.
- Brackett, Michael. Notes on tarif tree volume computation. Resour. Manage. Rep. 24. Olympia, WA: State of Washington, Department of Natural Resources; 1973. 26 p.
- Bruce, David. Metrication—what's next? J. For. 74(11): 737-738; 1976.
- Bruce, David. Yield differences between research plots and managed forests. J. For. 75(1): 14-17; 1977.
- Bruce, David. Where is the ground? In: Growth of single trees and development of stands: Proceedings, joint meeting of working parties S4.01-02 and S4.02-03, International Union of Forestry Research Organizations; 1979 September 14-15; Vienna. [Place of publication unknown]: [Publisher name unknown]; 1980: 49-50.
- Bruce, David; Curtis, Robert O.; Vancoevering, Caryanne. Development of a system of taper and volume tables for red alder. For. Sci. 14(3): 339-350; 1968.
- Bruce, Donald. A method of preparing timber-yield tables. J. Agric. Res. 32(6): 543-557; 1926.
- Bruce, Donald. Some transformations of the Behre equation of tree form. For. Sci. 18(2): 164-166; 1972.
- Cao, Quang V.; Burkhart, Harold E.; Max, Timothy A. Evaluation of two methods for cubic-volume prediction of loblolly pine to any merchantable limit. For. Sci. 26(1): 71-80; 1980.

- Carbonnier, Charles; Fries, Joran. Permanent plots in Swedish growth and yield research. In: Fries, J., ed. Permanent plots in forestry growth and yield research. Subject Group S4.01. Research Notes 43. Stockholm: International Union of Forestry Research Organizations, Royal College of Forestry, Department of Forest Yield Research; 1976: 50-56.
- Chambers, Charles J., Jr. Predicting dbh from stump dib and stump height for second growth Douglas-fir. DNR Note 25. Olympia, WA: State of Washington, Department of Natural Resources; 1978. 2 p.
- Clutter, Jerome L.; Jones, Earle P., Jr. Prediction of growth after thinning in old-field slash pine plantations. Res. Pap. SE-217. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1980. 14 p.
- Curtis, Robert O. Height-diameter and height-diameter-age equations for second-growth Douglas-fir. For. Sci. 13(4): 365-375; 1967a.
- Curtis, Robert O. A method of estimation of gross yield of Douglas-fir. For. Sci. Monogr. 13; 1967b. 24 p.
- Curtis, Robert O.; Arney, James D. Estimating d.b.h. from stump diameters in second-growth Douglas-fir. Res. Note PNW-297. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1977. 7 p.
- Curtis, Robert O.; Bruce, David. Tree heights without a tape. J. For. 66(1): 60-61; 1968.
- Curtis, Robert O.; Clendenen, Gary W.; DeMars, Donald J. A new stand simulator for coast Douglas-fir: DFSIM user's guide. Gen. Tech. Rep. PNW-128. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 79 p.
- Curtis, Robert O.; DeMars, Donald J.; Herman, Francis R. Which dependent variable in site index-height-age regressions? For. Sci. 20(1): 74-87; 1974.
- Decourt, N. Protocole d'installation et de mesure des placettes de production semi-permanentes: Procedures for installation and measurement of semi-permanent yield plots. [Place of publication unknown], France: Centre National de Recherches Forestieres (INRA); 1973. 25 p.
- Demaerschalk, J. P.; Kozak, A. The whole-bole system: a conditioned dual-equation system for precise prediction of tree profiles. Can. J. For. Res. 7(4): 488-497; 1977.
- Demaerschalk, Julien P.; Kozak, Antal. Dbh measurements and conversions in the metric system. For. Chron. 58(4): 173-175; 1982.
- Fabricius, L.; Oudin, A.; Guillebaud, W. H. Outlines for permanent sample plot investigations. [Place of publication unknown]: International Union of Forest Research Organizations; 1936. 33 p.
- Forestry Commission. Sample plot code. London: (British) Forestry Commission; 1979. Unpaged.
- Gray, H. R. The form and taper of forest-tree stems. Inst. Pap. 32. Oxford: Oxford University, Imperial Forestry Institute; 1956. 79 p.

- Grosenbaugh, L. R. Optical dendrometers for out-of-reach diameters; a conspectus and some new theory. *For. Sci. Monogr.* 4; 1963. 47 p.
- Hahn, Jerold H.; Leary, Rolfe A. Potential diameter growth functions. In: A generalized forest growth projection system applied to the Lake States region. Gen. Tech. Rep. NC-49. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1979: 22-26.
- Haig, I. T. Short cuts in measuring tree heights. *J. For.* 23(11): 941-944; 1925.
- Hamilton, G. J. Permanent sample plots in Britain. In: Fries, J., ed. Permanent plots in forestry growth and yield research. Subject Group S4.01. Research Notes 43. Stockholm: International Union of Forestry Research Organizations, Royal College of Forestry, Department of Forest Yield Research; 1976: 75-81.
- Hegyi, F. Optimum plot dimensions for experimental designs in jack pine stands. Sault Ste. Marie, ON: Canadian Forestry Service, Department of the Environment, Great Lakes Forest Research Centre; 1973. 13 p.
- Holdaway, Margaret R.; Leary, Rolfe A.; Thompson, Jerrilyn LaVarre. Estimating mean stand crown ratio from stand variables. In: A generalized forest growth projection system applied to the Lake States region. Gen Tech. Rep. NC-49. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1979: 27-30.
- Hummel, F. C.; Locke, G. M. L.; Jeffers, J. N. R.; Christie, J. M. Code of sample plot procedure. *For. Comm. (G. B.) Bull.* 31; 1959. 113 p.
- Jaakola, Sipi. On the use of variable size plots for increment research. In: Proceedings 14th world congress of the International Union of Forestry Research Organizations. Div. 6, Sect. 25; [Date of meeting unknown]. [Place of publication unknown]: [Publisher name unknown]; 1967: 370-378.
- Jeffers, J. N. R. Experimental design and analysis in forestry research. [Place of publication unknown]; International Union of Forest Research Organizations; 1959. 172 p.
- Keen, F. P. Climatic cycles in eastern Oregon as indicated by tree rings. *Mon. Weather Rev.* 65(5): 175-188; 1937.
- Kozak, A.; Munro, D. D.; Smith, J. H. G. Taper functions and their application in forest inventory. *For. Chron.* 45(4): 458-463; 1969.
- Krumland, Bruce; Wensel, Lee C. Concepts, design, and uses of coastal growth models. Res. Note 14. Berkeley, CA: University of California, College of Natural Resources; 1980. 7 p.
- McArdle, R. E.; Meyer, W. H.; Bruce, D. The yield of Douglas-fir in the Pacific Northwest. Tech. Bull. 201 (rev.). Washington, DC: U.S. Department of Agriculture; 1961. 24 p.
- McClure, Joe P. Predicting tree d.b.h. from stump measurements in the Southeast. Res. Note SE-99. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1968. 4 p.
- McEwen, A. D. Yield research plots of the Forest Research Institute. In: D. A. Elliot, ed. Mensuration for management planning of exotic forest plantations. Symp. 20. Rotorua, New Zealand: New Zealand Forest Service, Forest Research Institute; 1979: 253-301.

- Marckworth, Gordon D.; McKay, Donald; Gross, W. C. Report No. VIII. Techniques for establishing permanent growth plots in the Douglas-fir region. In: Reports of the West Coast Forestry Procedures Committee on Various Recommended Forest Practices and Techniques. Portland, OR: Western Forestry and Conservation Association; 1950: 59-67.
- Martin, A. Jeff. Taper and volume equations for selected Appalachian hardwood species. Res. Pap. NE-490. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1981. 22 p.
- Martin, George L. A method for estimating ingrowth on permanent horizontal sample points. *For. Sci.* 28(1): 110-114; 1982.
- Max, T. A.; Burkhart, H. E. Segmented polynomial regression applied to taper equations. *For. Sci.* 22(3): 283-289; 1979.
- Montana, Carlos; Ezcurra, Exequiel. Simple instrument for quick measurement of crown projections. *J. For.* 78(11): 699; 1980.
- Myers, C. C.; Beers, T. W. Point sampling for forest growth estimation. *J. For.* 66(12): 927-929; 1968.
- Myers, Clifford A. Yield tables for managed stands with special reference to the Black Hills. Res. Pap. RM-21. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 20 p.
- Myers, Clifford A. Field and computer procedures for managed-stand yield tables. Res. Pap. RM-79. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1971. 24 p.
- Ormerod, D. W. A simple bole model. *For. Chron.* 49(2): 136-138; 1973.
- Osborne, James G.; Schumacher, Francis X. The construction of normal-yield and stand tables for even-aged timber stands. *J. Agric. Res.* 51(6): 547-564; 1935.
- Reukema, Donald L. Some effects of freeze injury on development of Douglas-fir. *Northwest Sci.* 38(1): 14-17; 1964.
- Robertson, W. M.; Mulloy, G. A. Sample plot manual. Misc. Ser. 4. Ottawa, ON: Dominion Forest Service, Canadian Department of Mines and Resources; 1944. 60 p. plus tables.
- Robertson, W. M.; Mulloy, G. A. Sample plot methods. Ottawa, ON: Dominion Forest Service, Canada Department of Mines and Resources, Ottawa; 1946. 69 p.
- Robinson, D.W. A special forestry transit. *J. For.* 60(3): 202-204; 1962.
- Shepperd, Wayne D. An instrument for measuring tree crown width. Res. Note RM-229. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1973. 3 p.
- Smith, J. Harry G. Use of small plots can overestimate upper limits to basal area and biomass. *Can. J. For. Res.* 5(3): 503-505; 1975.
- Staebler, George R. Standard computations for permanent sample plots. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1954. 14 p.

- Stage, Albert R. A cruising computer for variable plots, tree heights, and slope corrections. *J. For.* 57(11): 835-836; 1959.
- Stage, Albert R. Prognosis model for stand development. *Res. Pap. INT-137*. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 32 p.
- Synnott, T. J. A manual of permanent plot procedures for tropical rain forests. *Trop. For. Pap. 14*. Oxford: University of Oxford, Commonwealth Forestry Institute; 1979. 67 p.
- Turnbull, K. J.; Little, Gene Roy; Hoyer, Gerald E. Comprehensive tree-volume tarif tables. 3d ed. Olympia, WA: State of Washington, Department of Natural Resources; 1980. 13 p. plus tables. 3d edition written by Charles J. Chambers and Bruce W. Foltz; edited by Julie A. McLaughlin.
- U.S. Department of Agriculture, Forest Service. Sample plots in silvicultural research. Circ. 333. Washington, DC; 1935. 88 p.
- Vuokila, Yrjo. Functions for variable density yield tables of pine based on temporary sample plots. Helsinki: Communicationes Instituti Forestalis Fenniae 60.4; 1965. 86 p.
- Western Forestry and Conservation Association. A set of recommended parameters and measurement instructions for field records of permanent growth plots. In: Reimer, D. R., chairman. Standards of measure and data sharing: report of the Committee of Standards of Measure and Data Sharing (COSMADS). Portland, OR: Western Forestry and Conservation Association; 1977. 7 p.
- Wheeler, P. R. Penta prism caliper for upper-stem diameter measurements. *J. For.* 60(12): 877-878; 1962.

## Appendix

### Checklist of Needed Plot and Tree Measurement Information

The following list is taken from the current version of the Plot Data Management System (PDMS). This is still under development and is subject to change; readers may not wish to follow the details. It does, however, indicate items that should be recorded in some comparable manner.

#### **Header (index) information.—**

Installation number

Plot number

Status: active, abandoned, destroyed

Plot age b.h., at first measurement

Site index

Site index system used

Plot area

Plot shape

Stem mapped: yes or no

Stand origin: natural, planted, seeded (if known, note spacing, seed source, etc., under general comments)

Primary species

Secondary species

Location: forty, section, township, range, State

Elevation

Aspect, azimuth (N = 360)

Slope percent

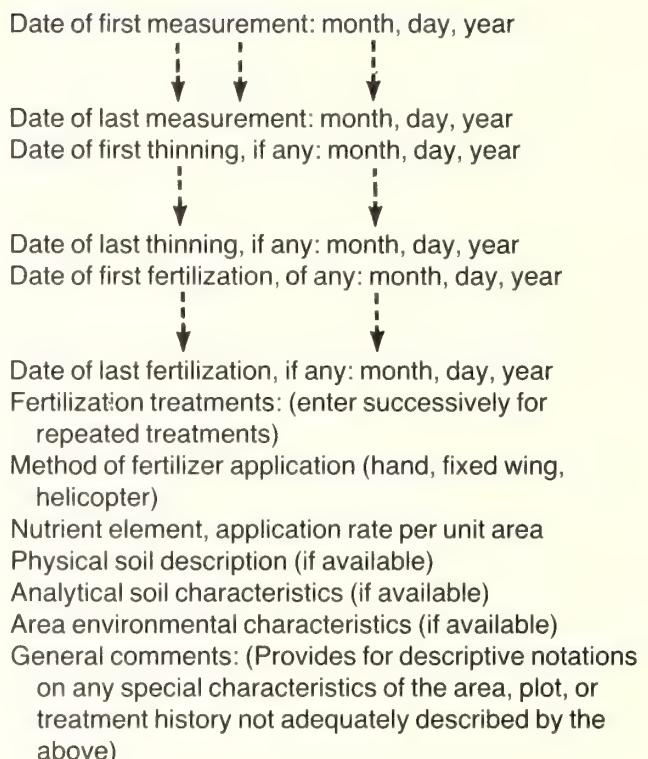
Slope position

Local name of installation

Measurement units: English vs. metric

Organization responsible

Project identification



### **Individual tree records.—**

Installation number

Plot number

Tree number

Species

Age b.h. as of first plot measurement (sample trees only)

Stem map coordinates (stem-mapped plots only)

Number of measurements on plot

Tree measurement information to be recorded for each successive measurement:

D.b.h.

Height (height sample trees only)

Height to live crown (height sample trees only, optional)

Crown class code

Tree status code

Tree damage, location (optional)

Tree damage, cause, general (optional)

Tree damage, cause, specific (optional)

See "PDMS Tree Classification Codes," page 48, for code definitions as used in the 1982 version of PDMS.

### **Standard USDA Forest Service Species Codes for Western Species<sup>1/</sup>**

1 Unclassified Softwoods	93 Engelmann Spruce	201 Big cone Douglas-fir	542 Oregon Ash
4 Unclassified Hardwoods	94 White Spruce	202 Inland Douglas-fir	631 Tan Oak
11 Pacific Silver Fir	95 Black Spruce	204 Eastslope Rocky Mtn	740 Cottonwood Species
15 White Fir	96 Blue Spruce	Douglas-fir	741 Balsam Poplar
17 Grand Fir	98 Sitka Spruce	205 Coastal Douglas-fir	746 Quaking Aspen
18 Corkbark Fir	101 Whitebark Pine	211 Coast Redwood	747 Black Cottonwood
19 Subalpine Fir	102 Bristlecone Pine	212 Giant Sequoia	760 Cherry Species
20 California Red Fir	103 Knobcone Pine	231 Pacific Yew	800 Oak Species
21 Shasta Red Fir	104 Foxtail Pine	242 Western Red Cedar	803 Arizona White Oak
22 Noble Fir	106 Pinyon Pine	251 California Torreya	805 Canyon Live Oak
41 Port-Orford Cedar	108 Lodgepole Pine	263 Western Hemlock	807 Blue Oak
42 Alaska Yellow Cedar	109 Coulter Pine	264 Mountain Hemlock	810 Emory Oak
51 Arizona Cypress	112 Apache Pine	310 Maple Species	814 Gambel Oak
60 Juniper Species	113 Limber Pine	312 Big Leaf Maple	815 Oregon White Oak
62 California Juniper	114 Mexican White Pine	313 Box Elder	818 California Black Oak
63 Alligator Juniper	116 Jeffrey Pine	350 Alder Species	821 California White Oak
64 Western Juniper	117 Sugar Pine	351 Red Alder	829 Mexican Blue Oak
65 Utah Juniper	118 Chihuahua Pine	361 Pacific Madrona	839 Interior Live Oak
66 Rocky Mtn Juniper	119 Western White Pine	376 W. Paper Birch	920 Willow Species
71 Tamarack	120 Bishop Pine	377 Alaska Paper Birch	981 Oregon Myrtle
72 Subalpine Larch	122 Ponderosa Pine	378 NW Paper Birch	999 Noncommercial Species Not
73 Western Larch	124 Monterey Pine	431 Golden Chinkapin	Coded in other Specific Codes
81 Incense Cedar	127 Digger Pine	492 Pacific Dogwood	Such as Vine Maple, Cascara,
92 Brewer Spruce		540 Ash Species	Etc.

<sup>1</sup> Quoted from Forest Survey Handbook. Forest Service Handbook FSH 4813.1, March 1967.

## PDMS Tree Classification Codes

The following system of tree classification codes is that used in the 1982 version of the PDMS system.

Note that although the system provides for six digits of information, including very detailed information on tree condition and cause of damage, only the first two digits are necessary for operation of summary programs and are mandatory for all tree measurements.

This system may not meet all needs, but it does illustrate characteristics needed in any system. It is sufficiently general that with minor modifications it should meet most needs.

For all classifications, programs will assign code "0" if no other entry is present.

### 1. Crown class

- 0 No estimate
- 1 Dominant
- 2 Codominant
- 3 Intermediate
- 4 Suppressed
- 5 Understory
- 6 Overstory
- 7 Off-plot tree

Codes 5, 6, and 7 are necessary for operation of PDMS and **must** be entered when applicable. Code 7 has priority over all other crown class designations (that is, if both 7 and another code apply, record 7). Code 5 is a tree in an even-aged stand which is clearly of a younger age class than the main canopy. Code 6 is a tree in an even-aged stand that is recognized as substantially older than the average age of the main canopy. Code 7 is a site tree or buffer strip tree located off the plot proper; these trees may be measured for site estimates or included in stem maps but are excluded from plot summaries.

### 2. Tree status

- 0 Live
- 1 Live cut
- 2 Dead
- 3 Ingrowth
- 4 New tree (that is, a tree missed in previous measurement)
- 5 Dead cut, salvable

- 6 Live tree with measured height, not suitable for height-diameter curves or site estimates
- 7 Both site and crop tree
- 8 Site tree
- 9 Crop tree

Codes 1 through 6 are essential to PDMS and **must** be entered when applicable. Codes 7, 8, and 9 are not essential to the system but should be recorded when applicable and override code 0. Codes 1 through 6 have priority over codes 7, 8, and 9. (Dead or cut trees are identified as site or crop trees by a summary program check on classification at the previous measurement.) Codes 7, 8, and 9 are treated as code 0 by PDMS in summary computations. Programs will treat a code 5 tree as code 2 and include it in mortality if the tree was alive at the immediately preceding measurement; if coded 2 at the immediately preceding measurement, the tree will be excluded from mortality totals for the current measurement.

- 3. Location and nature of damage or cause of death (code only the most serious damage)
  - 0 No damage or no information
  - 1 Damage present, location and nature unspecified
  - 2 Tip
  - 3 Foliage
  - 4 Limbs
  - 5 Bole, other than 2 or 6
  - 6 Basal
  - 7 Roots
  - 8 Leaning or bent tree
  - 9 Down tree

These codes and those for severity and cause of damage (classifications 4, 5, and 6 below) are not essential to operation of standard PDMS programs. It is desirable to include the classifications for location and severity (3 and 4) at least for the conditions that render a tree unsuitable for use as a height-diameter sample or as a site tree. Otherwise, one may use all, some, or none of those codes as desired.

<b>4. Severity of damage</b>		<b>4 Root diseases</b>	0 Unknown or unspecified
0 Unspecified		1-9 User defined	1-9 User defined
1 Minor		0 Unknown or unspecified	0 Unknown or unspecified
2 Moderate		1 Defoliators	1 Defoliators
3 Severe		2 Bark beetles	2 Bark beetles
Where more than one type or location of damage is present, rate "severity" as the combined effect of all damage—minor if damage is noticeable but judged unlikely to have a significant long-term effect; moderate if the tree is judged likely to survive but with substantially reduced growth rate or value; severe if the tree is judged likely to die or become unmerchantable.		3 Sucking insects	3 Sucking insects
<b>5. Cause and nature of damage—general</b>	<b>6. Cause and nature of damage—specific</b>	<b>4-9 User defined</b>	4-9 User defined
0 Unknown or unspecified	0 Unknown or unspecified	0 Unknown or unspecified	0 Unknown or unspecified
1 Human activities	0 Unknown or unspecified	1 Deer, elk	1 Deer, elk
2 Crown diseases and abnormalities	1 Logging	2 Bear	2 Bear
3 Bole diseases and abnormalities	2 Foliage sprays	3 Livestock	3 Livestock
	3 Bole treatments	4 Porcupine	4 Porcupine
	4 Root and soil treatments	5 Mountain beaver	5 Mountain beaver
	5 Pruning <sup>2</sup>	6 Other small mammals	6 Other small mammals
	6-9 User defined	7 Birds	7 Birds
	0 Unknown or unspecified	8-9 User defined	8-9 User defined
	1 Unhealthy appearance	0 Unspecified	0 Unspecified
	2 Foliage diseases	1-9 User defined	1-9 User defined
	3 Mistletoe	0 Unspecified	0 Unspecified
	4-9 User defined	1 Wind	1 Wind
	0 Unknown or unspecified	2 Snow, ice	2 Snow, ice
	1 Bole rots	3 Freeze	3 Freeze
	2 Multiple stems and forks	4 Drought	4 Drought
	3 Stem cankers and mistletoe	5-9 User defined	5-9 User defined
	4 Sweep and crook	0 Unspecified	0 Unspecified
	5 Dead or broken top	1-9 User defined	1-9 User defined
	6 Epicormic branching		
	7 Fluting		
	8-9 User defined		

<sup>2</sup> Note: Code 5 is recorded at initial measurement of any pruned tree. If subsequently coded as damaged by other causes, it is still identifiable by a summary program check for code 5 at previous measurements.

## **Field Tree Measurement Forms and Height Measurement Procedures**

**Plot measurement record form.**—A standard form, which can also serve as a data entry document, should be used for field measurements. For remeasurements, the information needed for tree identification plus previous measurement values needed to provide a check against measurement errors must be entered before fieldwork.

Several organizations are now using computer-produced forms for this information.

Figure 7 is based on one of these forms, modified to conform to the standards and coding system used in the 1982 version of PDMS. (Although this particular variation has not yet been implemented at the Forestry Sciences Laboratory at Olympia, an earlier version has been in use for several years.)

The successive fields represent:

**TREE #:** tree identification number, preprinted for all trees recorded at the previous measurement. Final digit is "0" for trees present at initial measurement (can be left blank on field form, if preferred); subsequent ingrowth trees are assigned a number determined as that of the nearest initial tree + a nonzero integer from 1 to 9.

**SP:** tree species, coded by standard USDA Forest Service three-digit species code (see p. 47). Preprinted.

**AGE BH:** tree age at breast height, as of the year of plot establishment. Preprinted if determined at the date of a previous measurement.

**DIAMETER:**

"74"—previous measurement, 1974 in this case. 1974 diameters preprinted on forms.

"76"—previous measurement, 1976 in this case. Preprinted.

Blank columns: used for entry of new field measurements of d.b.h. as illustrated. Enter measurements to 0.1 unit (inches or centimeters). Enter year of measurement in column heading.

**H:** total height of height sample trees. When heights are determined by one of the clinometer methods, this value is transcribed from the height measurement field sheet (fig. 10), after completion of field measurement and before data are entered into the computer system. If heights are measured with a height pole, heights are entered directly on this form. Last column to be used only if height is measured to nearest 0.1 unit.

**CC:** crown class.

"76"—value recorded at previous measurement, 1976 in this case. Preprinted.

Blank column—used for entry of new field measurement, as shown.

**STAT:** tree status (see tree classification codes, p. 48).

"76"—status code from previous measurement, 1976 in this case.

Blank column—used for entry of new field measurement as illustrated. Enter year in heading.

**DAMAGE:** Damage classification codes (see p. 48-49).

"76"—severity code from previous measurement, 1976 in this case. Preprinted.

Blank columns—used for entry of new field observations. "Loc" = location; "Sev" = severity; "Cause" = cause, general; "Spec" = cause, specific.

**HLC:** height to base of live crown. When determined by one of the clinometer methods, this value is transcribed from the height measurement field sheet (fig. 10), after field measurements are completed and before data are entered into the computer system. It can be entered directly when measured with a height pole.

Last column to be used only if measured to 0.1 unit.

**Tree coordinates:** X and Y coordinates of tree. Preprinted if plot has previously been stem mapped. Left blank and available for "Notes" if plot is not stem mapped.

**NOTES:** Blank space for any miscellaneous information not covered by specified items, or for reference to explanatory notes elsewhere, if any.

**Height measurement form and measurement procedures.**—Sample tree height measurements are normally obtained as a separate operation after measurement of diameters of all trees on the plot. The diameter record is used as the basis for selecting or modifying the sample of trees to be measured for heights.

A form for recording height measurements in the field is given in figure 10. The form is designed for use of either of two common height measurement procedures described in figures 8 and 9. (If heights are measured with a height pole, values are entered directly on the plot measurement form (fig. 7).)

Numbered columns on the form (fig. 10) represent the following:

1. Tree identification number for each tree in the height sample.
2. D.b.h. of each tree.
3. Recorded height (H) at last measurement, if any.
4. Recorded height to live crown (HLC) at last measurement, if any. (Note: 1, 2, 3, and 4 may be either preprinted on the form or transcribed from a computer-generated list of trees measured for heights at the last measurement. This initial list must then be modified by any deletions and additions needed to obtain a satisfactory height sample for the current measurement.)
5. Slope distance from instrument to tree.
6. Angle to tip of tree.
7. Blank column, provided to allow for measurements to some other point, if wanted; for example, if height of the nth node from tip is wanted to provide an estimate of height growth in the last n years.
8. Angle to base of live crown.
9. Angle to tip of measurement pole (when using pole and clinometer method).
10. Length of portion of pole used in item 9.
11. Angle to lower aim point.
12. Height of lower aim point above ground.
13. Blank column provided for miscellaneous notes.
14. Total height of tree calculated from the above values.
15. Height to base of live crown calculated from the above values.

Checked on \_\_\_\_\_ by \_\_\_\_\_.

Heights transcribed to field record form on \_\_\_\_\_  
by \_\_\_\_\_.

Figure 10.—Field form for height measurements, for use with either tape and clinometer or pole and clinometer.

Values of H and HLC should be calculated in the field and compared with previous values (if any) recorded in columns 3 and 4. If differences appear unreasonable for the time involved and apparent lengths of leader and internodes, the heights in question should be remeasured to be sure that current measurements and calculation are correct. Any abnormal leader and internode lengths or other characteristics that would account for an apparently inconsistent previous value should be noted, as an aid to later data editing.

After field measurements are complete, the calculations in columns 14 and 15 should be checked for arithmetical errors and the values of H and HCL transcribed to the plot measurement record form. This serves as the data entry document.

### **Equipment Checklist for Field Plot Work**

Modify this checklist as needed for specific jobs:

Tatum holder

Pocket calculator (preferably programmable)

Extra battery pack for above

Field tally sheets (or recording device), with previous measurements, if any

Coordinate paper or standard form for sketch maps

Protractor

Engineer's pocket scale

Copy of study plan or establishment report

Manual or specifications with applicable measurement instructions and recording codes

Maps

Aerial photos

Pocket stereoscope

String, large cones (for delimiting plot boundaries and strips within plot)

Paint gun or pressurized paint cans; tube paint for marking boundaries, numbering trees, marking b.h. point

Lumber crayons, yellow

Lumber crayon holders

Nails, aluminum (for tags)

Prenumbered metal tags, in sequence (if tagging new plot)

Label maker with metal tape

Claw hammer

Aluminum wire (for tagging small trees, corner stakes)

Flagging, assorted colors

Bark scribe

Hatchet

Machete

Small maul (for driving stakes)

Stakes (metal or other permanent material, for marking plot corners and centers)

Pruning saw

Staple gun, staples, cards (if there may be a need to tag trees temporarily)

Pocket compass

Staff compass with staff

Steel tape, 150 ft or 60 m, with reel (for laying out plot boundaries and measuring base lines)

Tape repair sleeves or spare tape

Pocket cloth tape, 75 ft or 30 m

Range poles

Height pole

Clinometers of type appropriate for expected tree size

Tripod if required by above

Diameter tapes

Increment borers (two sizes) with extra bits

Increment core holders (plastic drinking straws or the equivalent)

Bark gage

Hand lens

Flashlight with extra batteries

Transit with tripod (initial plot layout)

Stakes, tacks (initial plot layout)

Plumb bobs (initial plot layout)

First aid kit

Packs for carrying equipment

## Plot Dimensions and Conversion Tables (Tables 1-4)

**Table 1—Dimensions of square plots of specified area**

English units				Metric units			
Area	Side	Diagonal	Semidiagonal	Area	Side	Diagonal	Semidiagonal
<u>Acre</u>				<u>Hectare</u>	<u>Meters</u>		
0.001	6.60	9.33	4.67	0.001	3.16	4.47	2.24
.01	20.87	29.52	14.76	.01	10.00	14.14	7.07
.05	46.67	66.00	33.00	.05	22.36	31.62	15.81
.10	66.00	93.34	46.67	.10	31.62	44.72	22.36
.15	80.83	114.32	57.16	.15	38.73	54.77	27.39
.20	93.34	132.00	66.00	.20	44.72	63.25	31.62
.25	104.36	147.58	73.79	.25	50.00	70.71	35.36
.30	114.32	161.67	80.83	.30	54.77	77.46	38.73
.40	132.00	186.68	93.34	.40	63.25	89.44	44.72
.50	147.58	208.71	104.36	.50	70.71	100.00	50.00
.75	180.75	255.62	127.81	.75	86.60	122.47	61.24
1.00	208.71	295.16	147.58	1.00	100.00	141.42	70.71

**Table 2—Dimensions of circular plots of specified area**

English units		Metric units	
Area	Radius	Area	Radius
<u>Acre</u>	<u>Feet</u>	<u>Hectare</u>	<u>Meters</u>
0.001	3.72	0.001	1.784
.01	11.78	.01	5.64
.05	26.33	.05	12.62
.10	37.24	.10	17.84
.15	45.60	.15	21.85
.20	52.66	.20	25.23
.25	58.88	.25	28.21
.3	64.50		
.4	74.47		
.5	83.26		

**Table 3—Multipliers to convert slope distance to horizontal distance and horizontal distance to slope distance <sup>1/</sup>**

Slope percent	$\cos\theta$ (ds to d)	$1/\cos\theta$ (d to ds)	Slope percent	$\cos\theta$ (ds to d)	$1/\cos\theta$ (d to ds)
5	0.999	1.001	60	0.857	1.156
10	.995	1.005	62	.850	1.177
15	.989	1.011	64	.842	1.187
			66	.835	1.198
20	.981	1.020	68	.827	1.209
22	.977	1.024			
24	.972	1.028	70	.819	1.221
26	.968	1.033	72	.812	1.232
28	.963	1.038	74	.804	1.244
			76	.796	1.256
30	.958	1.044	78	.788	1.268
32	.952	1.050			
34	.947	1.056	80	.781	1.281
36	.941	1.063	82	.773	1.293
38	.935	1.070	84	.766	1.306
			86	.758	1.319
40	.928	1.077	88	.751	1.332
42	.922	1.085			
44	.915	1.092	90	.743	1.345
46	.908	1.101	92	.736	1.359
48	.902	1.109	94	.729	1.372
			96	.721	1.386
50	.894	1.118	98	.714	1.400
52	.887	1.127			
54	.880	1.136	100	.707	1.414
56	.872	1.146			
58	.865	1.156			

<sup>1/</sup>(1) Slope distances to horizontal distance:  $d = ds \cdot \cos\theta$ , for  $\theta$  in degrees. (2) horizontal to slope distance:  $ds = d/\cos\theta$ , for  $\theta$  in degrees.

**Table 4—English and metric equivalents**

English or metric	=	Equivalent
1 inch	=	2.540 centimeters
1 meter	=	39.37 inches
1 mile	=	1.609 kilometers
1 kilometer	=	0.6214 mile
1 square foot	=	929.0 square centimeters
1 square foot	=	0.0929 square meter
1 square meter	=	10.76 square feet
1 acre	=	0.4047 hectare
1 hectare	=	2.471 acres
1 cubic foot	=	28.32 cubic decimeters
1 cubic foot	=	28.32 liters
1 ounce liquid	=	29.57 cubic centimeters
1 quart	=	0.9463 liter
1 liter	=	1.0567 quarts
1 cubic foot	=	0.02832 cubic meter
1 cubic meter	=	35.31 cubic feet
1 cubic foot/acre	=	0.06997 cubic meter/hectare
1 cubic meter/hectare	=	14.29 cubic feet/acre
1 pound avoirdupois	=	453.6 grams
1 kilogram	=	2.205 pounds
1 short ton	=	0.9072 tonne
1 long ton	=	1.016 tonne
1 tonne	=	2.205 pounds

Curtis, Robert O. Procedures for establishing and maintaining permanent plots for silvicultural and yield research. Gen. Tech. Rep. PNW-155. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 56 p.

This paper reviews procedures for establishing and maintaining permanent plots for silvicultural and yield research; discusses purposes, sampling, and plot design; points out common errors; and makes recommendations for research plot designs and procedures for measuring and recording data.

Keywords: Plot analysis, permanent sample plots, tree measurement, sample plot design.

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June 1983



# How To Reduce Injuries to Residual Trees During Stand Management Activities

Paul E. Aho, Gary Fiddler,  
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## **Authors**

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## **Abstract**

**Aho, Paul E.; Fiddler, Gary; Filip, Gregory M.** How to reduce injuries to residual trees during stand management activities. Gen. Tech. Rep. PNW-156. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 17 p.

Losses of trees and tree volume that result from decay initiated by mechanical injuries during stand management activities in the western United States are substantial. They can be reduced through improved logging methods and careful planning of other forest management activities.

**Keywords:** Logging damage, tree injury, decay (wood), forest damage/protection, intensive management.

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## **Introduction**

Intensive forest management, requiring frequent entries into stands, increases the probability that residual trees will be wounded. Logging during commercial thinning causes many injuries, but recreational activity in forests, which is increasing, also leads to wounding of trees, particularly around campgrounds. This report illustrates the types of wounds, damage, and decay losses found in residual trees on intensively managed forest areas of the western United States and recommends methods to lessen these impacts.

## Types of Damage

The most significant type of damage is direct mortality of residual trees (fig. 1). This occurs when harvested trees are felled against leave trees.



Figure 1.—A white fir killed when struck by a felled tree during a thinning operation.

Significant secondary volume losses occur from decay that follows wounding (fig. 2), including broken tops (fig. 3), caused by felled trees and mechanical equipment.

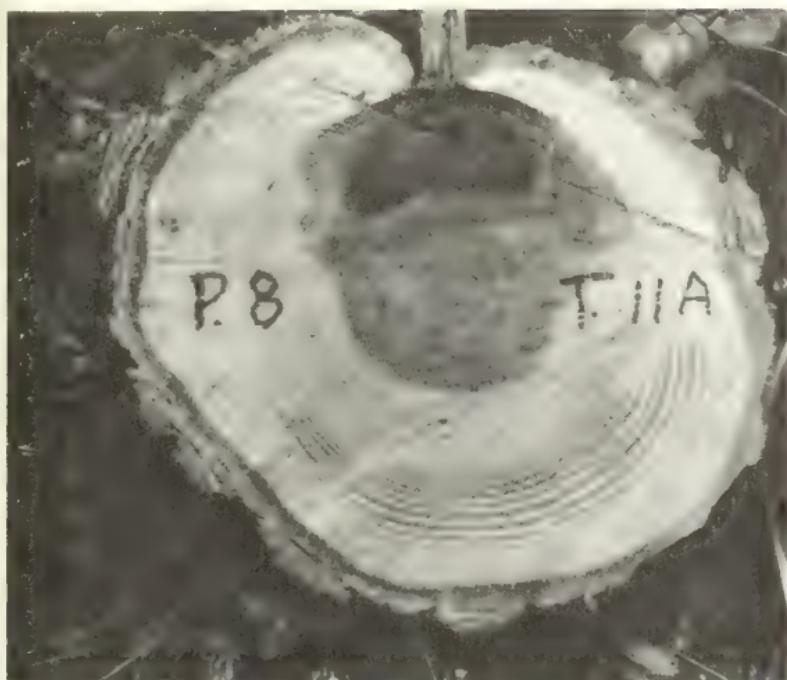


Figure 2.—Cross-section through a wound in white fir. Dark area indicates decay.



Figure 3.—Cross-section of white fir just below a broken top exposing decay associated with a logging injury.

Losses from decay are caused by fungi that invade wounds and stumps. Losses are increased when decay spreads through root contacts to neighboring trees (fig. 4).

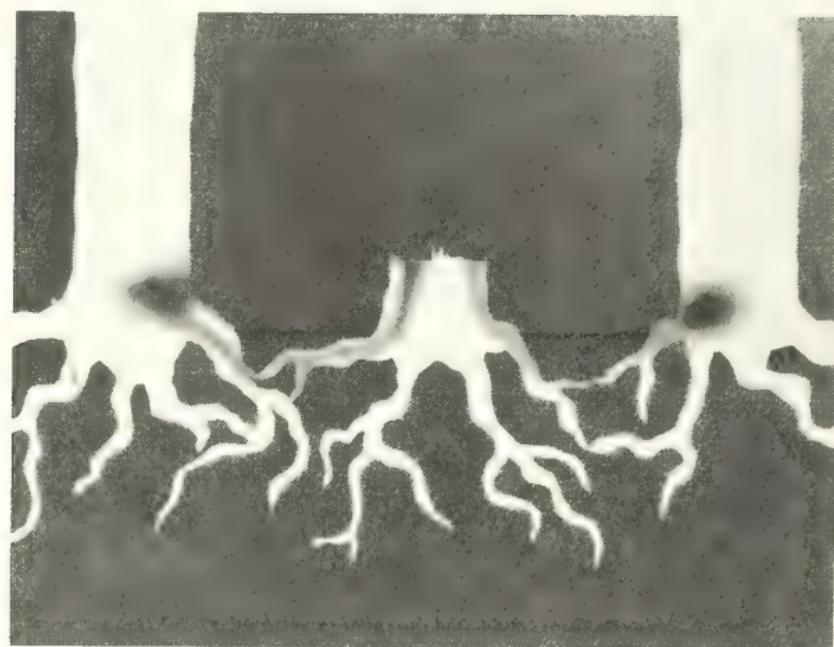


Figure 4.—Root rot spreads from stumps of infected trees to neighboring trees through root contacts.

In true firs and hemlocks, significant losses are caused by frost cracks and shake (fig. 5) that begin with wounds and by decay caused by the Indian paint fungus which is reactivated by wounding (fig. 6).

Another, less obvious loss results when volume growth is reduced because residual trees are unable to respond to release because of severe wounding or soil compaction.



Figure 5.—Cross-section of a grand fir showing wound-initiated frost cracks, wet-wood, and shake.



Figure 6.—Decay caused by Indian paint fungus associated with a logging wound. Injuries activate semi-dormant infections of this fungus, which may be present in certain tree species before they are wounded.

In recreation areas, wounding and subsequent decay may so weaken trees that they are hazardous to people and property (fig. 7).



Figure 7.—Damage to recreation facilities caused by a windthrown tree. Decay associated with an injury had weakened the tree.

## Factors That Determine Amount of Damage

Many factors, including environmental conditions, influence the incidence and extent of decay that follows wounding. The most important factors are tree species, size and type of wound, condition of wood exposed by the wound, and location of the wound.

### Species:

Most species with nonresinous wood, such as true firs and hemlocks, are more readily infected by decay fungi than are species with resinous wood, such as Douglas-fir and the pines. There are exceptions, however; spruces have resinous wood but are very susceptible to infection by decay fungi when wounded.

### Size and type of wound:

Large wounds are more likely to become infected than small wounds, and more decay is usually associated with large wounds than with small wounds (fig. 8).

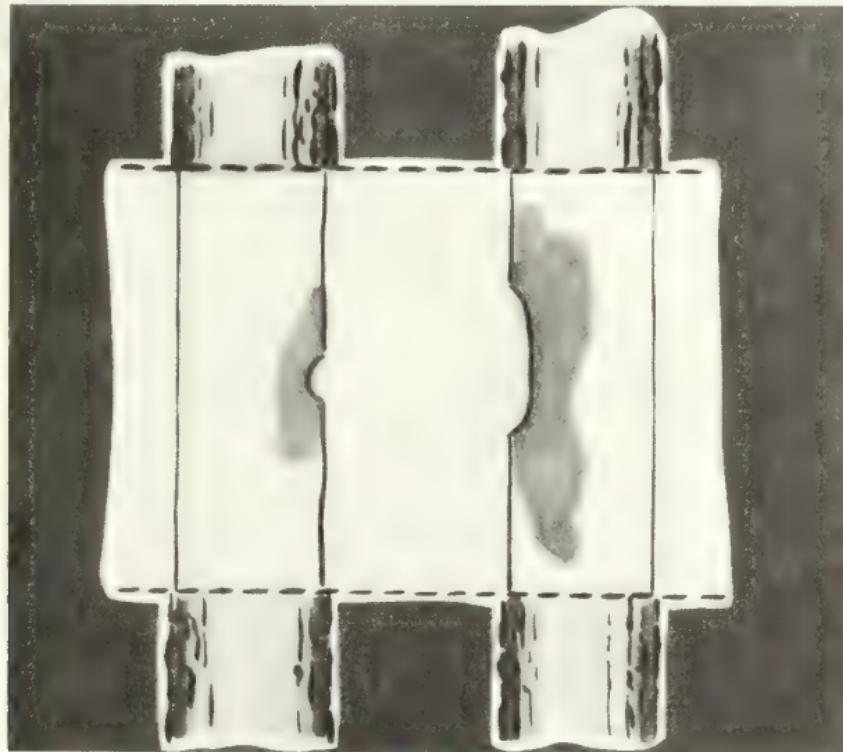


Figure 8.—Large wounds increase the likelihood of infection by decay fungi and increase the amount of decay.

Wounds in which the sapwood is gouged and splintered are more likely to be infected and have more decay than wounds that remove only the bark (fig. 9). If the wound surface is rough, it takes longer for new wood to grow over it.



Figure 9.—Gouge wounds (above) are more likely to become infected and have more decay than smooth wounds (below).



### **Location of wound:**

The closer a wound is to the ground the more likely it is to become infected and the more severe the infection. Wounds of roots or the base of the bole nearly always become infected, and the decay progresses more rapidly than in wounds higher above the ground (fig. 10).



Figure 10.—Basal or ground-contact wounds (above) nearly always become infected, and the rot usually progresses more rapidly than in wounds above the ground (below).



## Examples of Damage

Data from a recent study indicate that serious volume losses result when trees are wounded from operation of equipment. Table 1 shows high percentages of residual crop trees damaged during conventional logging. Many trees were damaged so badly they were no longer suitable for crop trees.

**Table 1—Logging damage to young-growth white fir and Douglas-fir residual trees in northern California stands thinned by conventional logging methods<sup>1/</sup>**

Species	Logging method	Residual trees	
		Wounded	Destroyed
-----Percent-----			
White fir	Skidder	22	2/
Douglas-fir	Tractor	35	15
White fir	Skidder	33	2/
Douglas-fir	Cable	46	8
White fir	Grapple skidder	50	15

<sup>1/</sup> Aho and others 1983.

<sup>2/</sup> No data taken.

Table 2 shows data collected in two white fir stands that were thinned with rubber-tired skidders. The figures for basal wounds are particularly significant.

**Table 2—Percent of residual trees wounded and the location of injuries in 2 northern California white fir stands thinned by conventional logging methods<sup>1/</sup>**

Species	Logging method	Trees damaged	Location of wounds		
			Basal	Bole	Crown
			Percent-----		
White fir	Skidder	22	74	15	11
White fir	Skidder	33	72	16	12

<sup>1/</sup> Aho and others 1983.

Table 3 shows what logging damage means in terms of volume loss caused by decay. In the stands we examined, board-foot decay losses in wounded firs already amount to 14 percent for white fir and nearly 7 percent for red fir. Losses will become much larger as decay progresses until the trees are harvested.

**Table 3—Decay losses associated with wounds in white and red fir trees sampled in 13 thinned stands in the Lassen National Forest, California<sup>1/</sup>**

Species	Trees wounded	Wounds infected	Loss expressed in—	
			Cubic feet	Board feet
			Number-----Percent-----	
White fir	186	231	100	4.5
Red fir	39	44	100	1.9

<sup>1/</sup> Aho and others 1983.

## How To Prevent Wounds

The best way to reduce decay and the resulting growth losses in residual trees is to prevent wounding during stand entries. A study in which logging was done using techniques designed to reduce injuries indicates that residual trees can be protected by action taken both during the planning process and during logging.

### Action to take during timber sale planning:

1. Restrict the logging season. Do not allow logging of thin-barked species such as true firs and hemlocks during spring and early summer when the sap is flowing and the bark is not tight.
2. Match the size and type of logging equipment to topography, tree size, and soil type and condition. On gentle terrain, use track-laying or rubber-tired vehicles no larger than necessary (fig. 11). On slopes steeper than 35 percent or on fragile soils, use cable systems (fig. 12).



Figure 11.—Using small skidders reduces injury to residual trees in young stands. Equipment suitable for old-growth stands is not suitable for young-growth stands, although it is often used for thinning.



Figure 12.—Small cable systems are suitable for logging young stands on steep slopes or fragile soils.

3. Mark "leave" trees rather than "cut" trees. This simple change calls attention to the residual trees and has significantly decreased damage to them.
4. Lay out skid trails before logging begins. Use straight-line trails only slightly wider than the skidding vehicle.
5. Designate "rub" trees, to be removed last, or leave cull logs along the edges of skid trails to protect residual trees.
6. Match maximum log length to spacing of the residual stand. Close spacing calls for relatively short logs, whereas wider spacing allows skidding of longer logs with minimal damage to residual trees. Cut trees into logs before skidding. Moving whole tree lengths increases damage to residual trees.

### Action to take during logging:

1. Most important is to gain the cooperation of the logger, who must be convinced that most damage to residual trees is unnecessary and will not be tolerated.
2. Log skid trails first. Cut stumps as low as possible so they will not shunt the skidding vehicle or logs sideways into residual trees.
3. Require directional felling. Trees should be felled about 45 degrees toward or away from skid trails (fig. 13).



Figure 13.—A thinned white fir stand in which the harvested trees have been directionally felled to reduce damage to residual trees when they are skidded.

4. Limb and top trees prior to skidding. Limb flush to the bole.
5. In some locations, especially in California, stumps of pines, true firs, and hemlock need protection against *Heterobasidion [Fomes annosus] annosum*. Treatment is particularly important in recreation areas where standing, but unsound, trees may become hazards to people and property.

The effectiveness of these practices was demonstrated in four northern California stands (table 4), where their application reduced damage to residual trees considerably compared with damage in table 1.

**Table 4—Logging damage in 4 stands in northern California thinned carefully to reduce injuries to residual trees** <sup>1/</sup>

Species	Logging Method	Residual trees wounded <i>Percent</i>
Ponderosa pine	Skidder	5
White fir	Tractor	11
White fir	Tractor	11
White fir	Tractor	14

<sup>1/</sup> Aho and others 1983.

Preventing wounding during stand entries also insures that stands (fig. 14) will be capable of responding favorably to the management treatments applied.

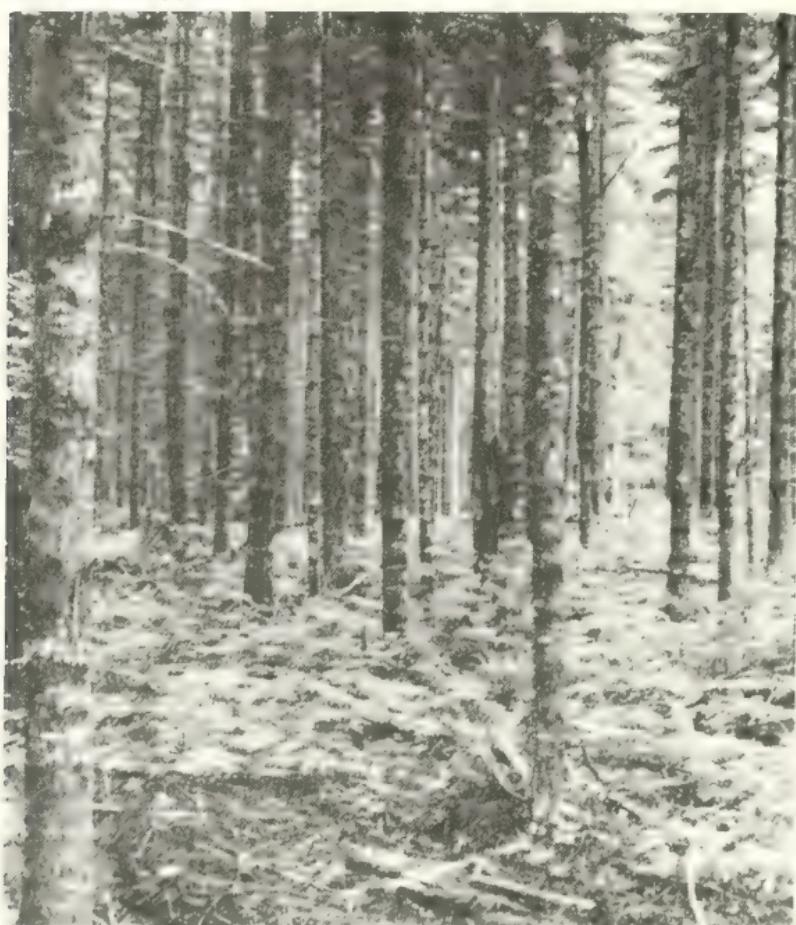


Figure 14.—Stand thinned using recommended logging methods.

Information in this report is also available in a slide talk of the same title prepared by the authors. It may be obtained from:

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## **Literature Cited**

**Aho, Paul E.; Fiddler, Gary; Srago, Mike.** Logging damage in thinned young-growth true fir stands in California and recommendations for prevention. Res. Pap. PNW-304. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983**. 8 p.

## **Metric Equivalents**

1 cubic foot = 0.028 cubic meter

1 board foot = 0.002 cubic meter





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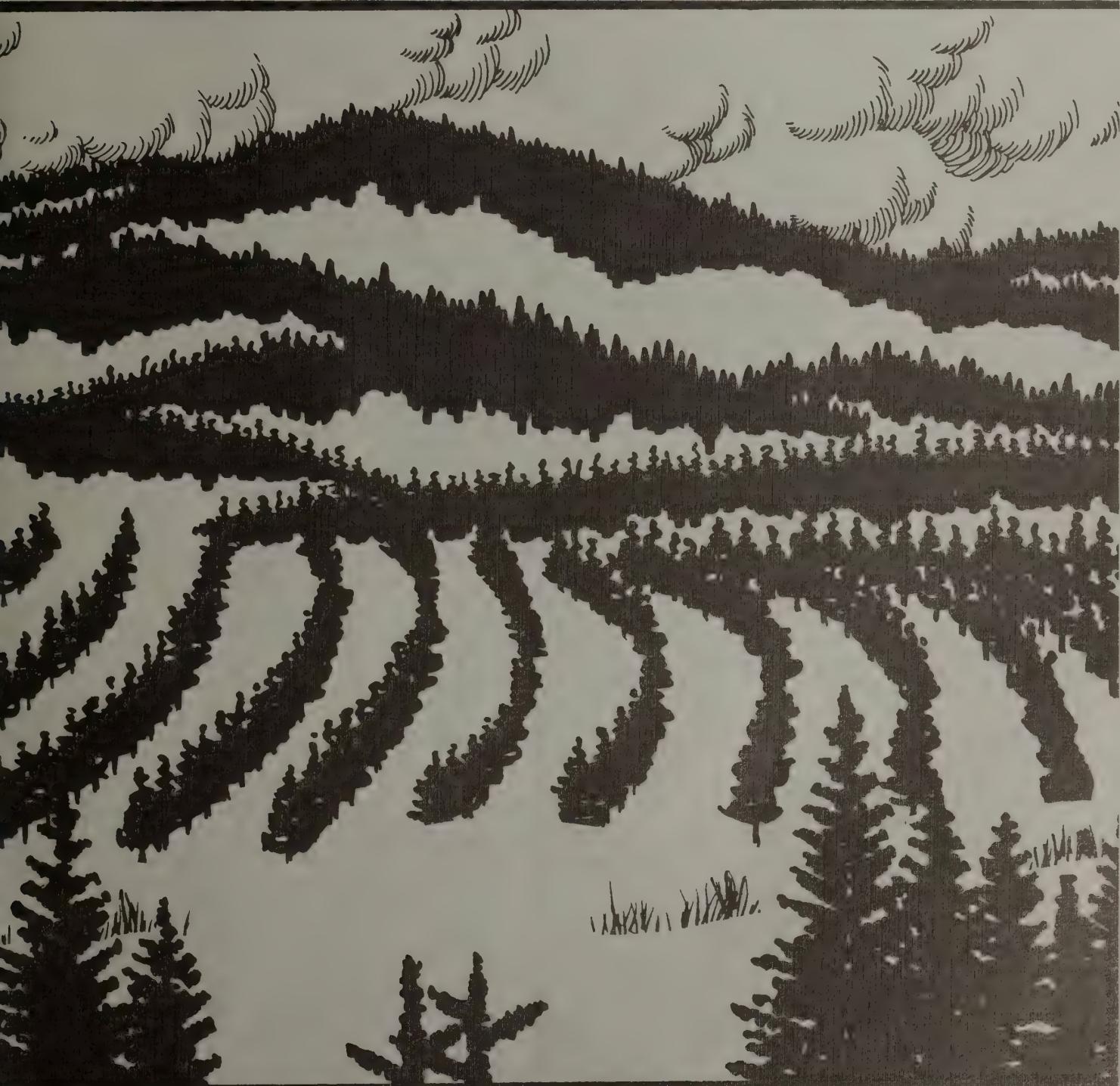
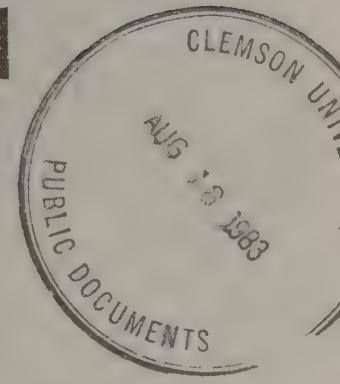
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# Lodgepole Pine: Regeneration and Management





## LODGEPOLE PINE: REGENERATION AND MANAGEMENT

Edited by  
Mayo Murray

The Proceedings of a Fourth International Workshop

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## INTRODUCTION

Anthony F. Gasbarro

Early in 1979, the School of Agriculture and Land Resources Management of the University of Alaska surveyed forest managers in a number of northern countries to identify topics of circumpolar interest in forest management. Responses most frequently centered on problems of forest regeneration. As a result we initiated what was to be a series of international workshops to address the problem of obtaining adequate and economical forest regeneration at high latitudes. Our initial efforts were financed by a generous grant from the United States Department of Agriculture, U. S. Forest Service.

The first international workshop was held in November 1979, in Fairbanks, Alaska. Representatives from Canada, Finland, Norway, Sweden, and Alaska discussed general problems related to forest regeneration in their respective countries. The second workshop, held in Umeå, Sweden, in August 1980, focused on Swedish attempts to deal with the problems of

forest regeneration. A third workshop, held in Prince George, British Columbia, Canada, in August 1981, dealt with Canadian efforts to address the forest regeneration issue. The fourth workshop took place at Hinton, Alberta, Canada, in August 1982 and dealt with the management of lodgepole pine in the boreal forest. This report contains the papers given at the 1982 workshop.

The meeting at Hinton, Alberta was sponsored by the Canadian Forest Service. The principal organizers of the workshop were Alex Gardner, Forestry Officer of the Canadian Forest Service, and John Powell, Program Manager, Environmental Forestry, Canadian Forest Service. The objective of the workshop was to review techniques and discuss problems related to lodgepole pine management in western Canada with the hope of providing insight to those forest managers wishing to introduce and/or manage lodgepole pine in other northern-latitude countries (i.e. Alaska, USA, Sweden and Finland). Sincere appreciation is expressed to the authors of the papers in this publication.

---

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The next workshop will be held in Fairbanks, Alaska, in August 1983. It will address the problem of site identification and classification at northern latitudes.



## NATURAL LODGEPOLE PINE IN WEST-CENTRAL ALBERTA PART I: REGENERATION STOCKING

Imre E. Bella

### INTRODUCTION

Natural lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) is generally considered to be a seral species and exhibits a very broad ecological amplitude. It commonly regenerates abundantly and rapidly following wildfire or scarification. Lodgepole pine is capable of rapid juvenile growth on a wide variety of forest sites, but overabundant regeneration often results in reduced tree growth and merchantable yield. Therefore, the usefulness of regeneration surveys could be much enhanced if they were to provide factual information on actual seedling densities in overstocked regeneration. This would facilitate the planning of any thinning treatments required to increase merchantable timber production. Many studies have shown that thinning a young, overdense lodgepole pine stand is the most effective stand treatment option for yield improvement.

Fertilization, in addition to regeneration stocking control and juvenile spacing, provides another opportunity to improve fiber production. Information is required on the kind, quantity, and timing of fertilizer application under a variety of stand conditions that produces the best returns on this investment.

### STOCKING – DENSITY RELATIONSHIP

When stocking standards are defined in terms of stocking percentages, those percentages imply a certain minimum number of established, acceptable seedlings per hectare. Although this specified minimum number of seedlings is an important guideline, the actual number may be considerably higher and dependent on the spatial pattern of the seedlings over the area.

Past studies (Bella 1976; Bella and DeFranceschi 1978) have shown that over 90% of lodgepole pine natural regeneration has a clumpy pattern whether it originates after logging and site preparation or after wildfire. This aggregation, or clumping, of

seedlings generally means a surplus of seedlings on some stocked quadrats over the number implied by the stocking percentage. The degree of clumping and thus the number of surplus seedlings may vary considerably and depends on several factors including seed source, seed bed, and weather (moisture) conditions.

Although factual data on the number of these extra seedlings would assist intelligent, early planning of density-control treatments, only a limited amount of information is available. Bella (1976) published information on average expected number of seedlings in relation to stocking percentage. In a follow-up report, Bella and DeFranceschi (1978) presented trends of relative frequencies of stocked quadrats with at least 1, 2, 3, etc. established seedlings in relation to stocking percentages for the major commercial forest types in western Alberta. Using the same data base, this paper takes the analysis one step further for lodgepole pine types and provides detailed information on seedling densities per ha. based on estimates from 4- and 8-m<sup>2</sup> quadrats, when those density estimates include only one, up to 2, 3, 4, ..., 9, or all coniferous seedlings per quadrat.

### THE SAMPLE

Data for this analysis were collected in the Foothills Section, mainly in the B.19a-Lower Foothills area (Rowe 1972), fig. 1 (over), where the major coniferous species are lodgepole pine, white spruce (*Picea glauca* (Moench) Voss), black spruce (*P. mariana* (Mill.) B.S.P.), balsam fir (*Abies balsamea* (L.) Mill.), and alpine fir (*A. lasiocarpa* (Hook.) Nutt.). They cover a large geographic area encompassing a considerable variation in soil and site conditions. Soil moisture was probably the most important single variable affecting seedling establishment and growth.

Sampling was conducted in the springs of 1975 and 1977 in cutover blocks approximately ten growing seasons after logging. These blocks, therefore, represented a range of stocking and stand conditions in the region. Ground treatment (drag-type scarification) had generally followed logging within a year. On each cutover block sampled, three 0.04-ha<sup>2</sup> square plots were established to represent low, average, and high stocking levels in that stand.

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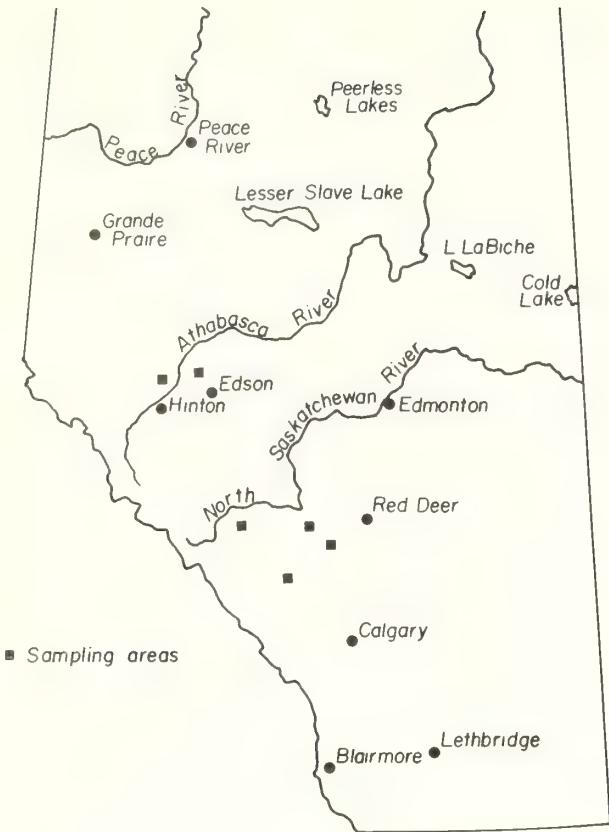


Figure 1.--General locations of sample plots.

The sample plots were subdivided into a grid of  $10 \times 10$  4-m $^2$  (1 milacre) quadrats. On each quadrat, all seedlings 2 and 3 years old or older as well as vigorous advance growth were tallied by species, and the health of each individual recorded.

Data collected by J. Soos (on file at the Northern Forest Research Centre) in 1966 in 8-year-old lodgepole pine near the Upper Saskatchewan Ranger Station (Rocky-Clearwater Forest) were also used. This was a complete tally (100% sample) of pine regeneration only by a 4-m $^2$  quadrat of a 15.5-ha area where the original lodgepole pine stand had been destroyed by fire 8 years earlier. For this analysis, this sample was partitioned into contiguous 36- x 36-m plots (i.e., an 18 x 18 matrix of 4-m $^2$  quadrats). A total of 85 plots was used in the analysis. Plots that had roads or logging trails preventing regeneration were excluded from the analysis.

## ANALYSIS

The number of seedlings per hectare in relation to stocking percentage was compiled from quadrat tallies on each plot considering only one, up to 2, 3, ...9 or all acceptable seedlings, viz, healthy 3-year-olds and older, and advanced growth per quadrat. Either pine or pine-spruce-fir were considered. Two quadrat sizes, 4-m $^2$  and 8-m $^2$ , were used. The data were summarized by 5% stocking classes and freehand curves were drawn to class means.

## RESULTS AND DISCUSSION

Figures 2 through 6 show trends of seedling densities per hectare in relation to stocking percentage when 1, 2, ..., 9 or all

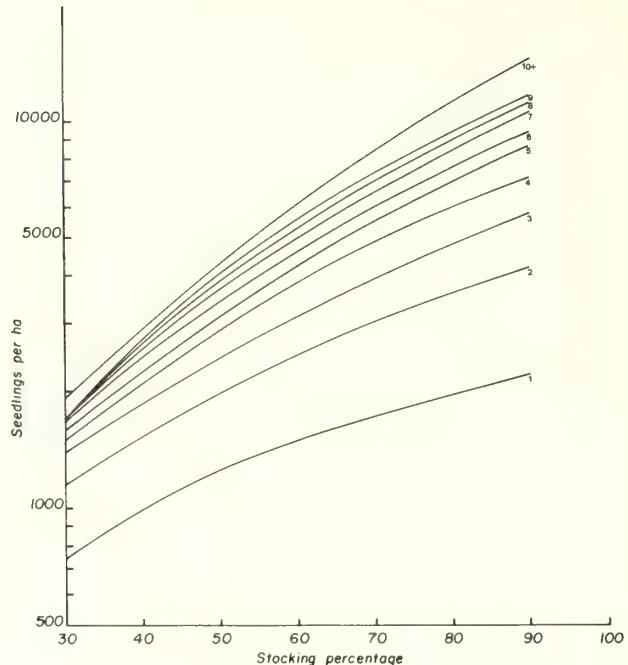


Figure 2.--Density-stocking relationships for pine after logging, based on 4-m $^2$  quadrats.

seedlings are considered. Figures 2 and 5 are based on 4-m $^2$  quadrats and those in figures 3, 4, and 6 on 8-m $^2$  quadrats. The implication of quadrat size in regeneration surveys in Alberta has been discussed at some length by Bella (1976).

These relationships indicate a substantially greater number of trees per unit area than is implied by a given stocking percentage. For instance, considering up to two pine trees per 4-m $^2$  quadrat means a density nearly twice as high at stocking levels above 50% than would be expected from the stocking percentage. At lower stocking, there are fewer extra seedlings, both in absolute and relative terms.

Increasing the number of trees counted per ha to 3, 4, ..., etc., after two trees means a fairly gradual increase in density per hectare; but there is a definite rise in the trend for "all" trees at higher stocking levels that indicates over-dense conditions. This suggests that, at higher stocking levels, a stocked quadrat often has two trees, although it may also have a clump of ten or more.

Essentially the same general relationship prevail when the trends are based on 8-m $^2$  quadrats (rather than 4-m $^2$ ), although, as expected, they show lower tree numbers at low and medium stocking levels; at over 80% stocking (figs. 2 and 3), the two sets of trends tend to converge.

No substantial differences in seedling densities were found between logged areas and those regenerating after wildfire (fig. 3 vs. fig. 4), although a midrange of stocking (60-80%) density levels were higher after logging than after fire. These higher densities may arise from the clumpiness of pine regeneration associated with postlogging site treatment.

Spruce and fir, in addition to pine, in the quadrat tally do not seem to have much effect on these relationships, although a few more extreme-density values have occurred at high stocking levels with the inclusion of these two other conifers.

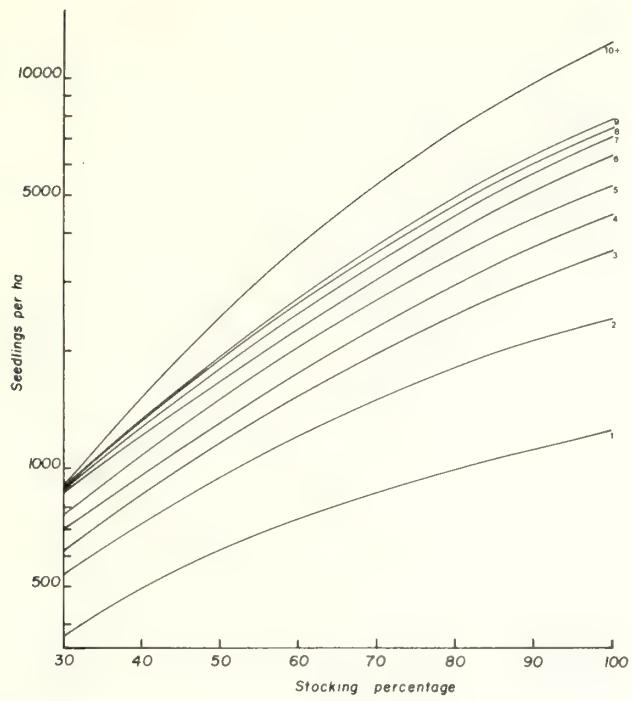


Figure 3.--Density-stocking relationships for pine after logging, based on 8-m<sup>2</sup> quadrats.

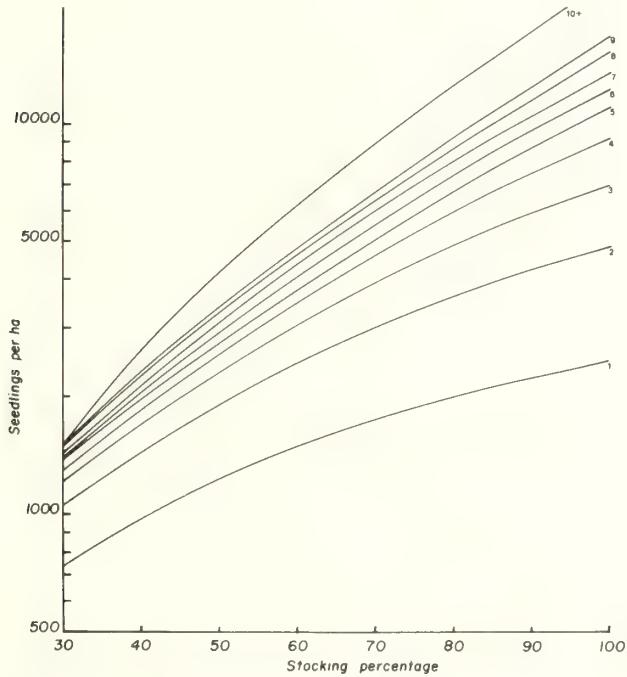


Figure 5.--Density-stocking relationships for pine-spruce-fir after logging, based on 4-m<sup>2</sup> quadrats.

## CONCLUSIONS

Clumping and excessive crowding of lodgepole pine regeneration requires factual information on seedling densities in order to plan thinning treatments that will enhance merchantable wood production. Such requisite data may be obtained during regeneration surveys with relatively little extra work. Besides its direct use, such information would provide data for developing guide curves for the more important sites, cover types, and postlogging treatment combinations which later may be used to estimate seedling densities from stocking percentages.

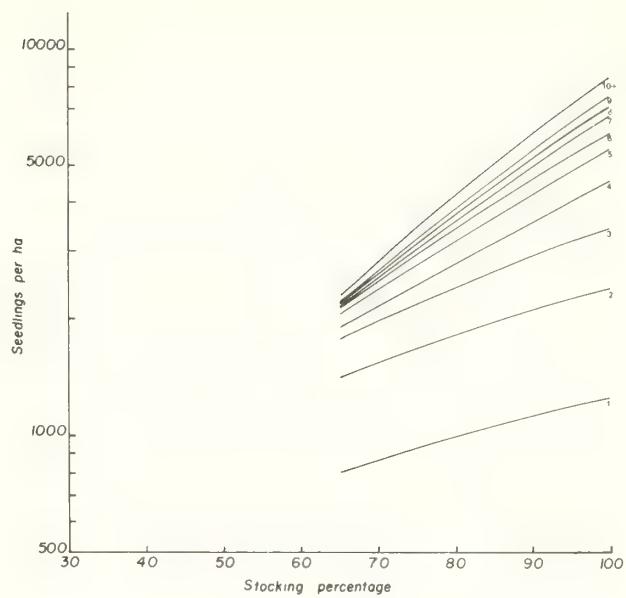


Figure 4.--Density-stocking relationships for pine after wildfire, based on 8-m<sup>2</sup> quadrats.

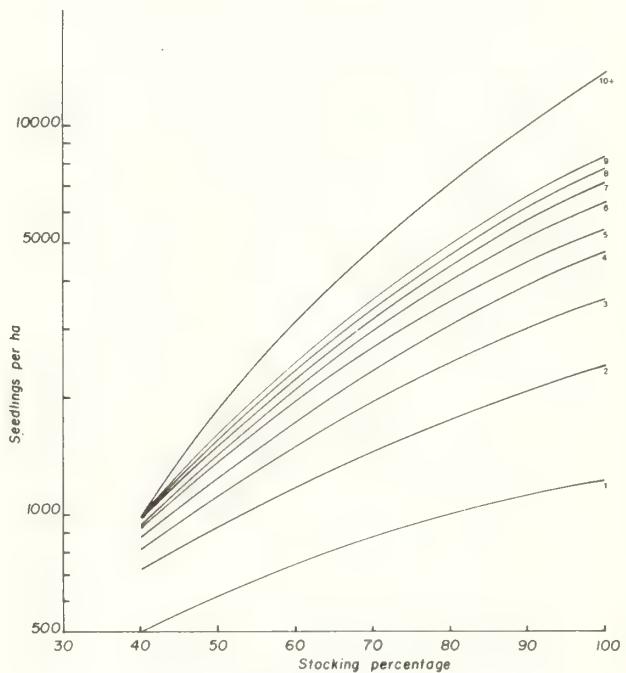


Figure 6.--Density-stocking relationships for pine-spruce-fir after logging, based on 8-m<sup>2</sup> quadrats.

## LITERATURE CITED

- Bella, I.E. Assessment of regeneration stocking standards used in Alberta. Inf. Rep. NOR-X-211. Edmonton, Alberta: Environ. Can., Can. For. Ser., North. For. Res. Cent.; 1976.
- Bella, I.E.; J.P. DeFranceschi. Assessment of regeneration stocking standards used in Alberta: a follow-up. Inf. Rep. NOR-X-211. Edmonton, Alberta: Environ. Can., Can. For. Serv., North. For. Res. Cent.; 1978.
- Rowe, J.S. Forest Regions of Canada. Pub. No. 1300. Edmonton, Alberta: Environ. Can., Can. For. Service.; 1972.

## NATURAL LODGEPOLE PINE IN WEST-CENTRAL ALBERTA PART II: JUVENILE SPACING

W. D. Johnstone

### INTRODUCTION

The juvenile growth and, ultimately, the harvest of natural lodgepole pine stands can be seriously reduced when excessive stand density results in severe intertree competition (Johnstone 1976). Smithers (1961) warns that stands containing over 5000 stems per hectare at 90 years of age will probably not provide a reasonable merchantable yield. Although apparently unable to thin itself, lodgepole pine, particularly at young ages, will respond favorably to precommercial thinning or juvenile spacing (Alexander 1956, 1960, 1965; Barrett 1961; Cole 1975; Dahms 1967, 1971a, 1971b, 1971c, 1973; Daniel and Barnes 1958; Johnstone 1981a, 1981b, 1982; Smithers 1957, 1961). This report updates, to 18 years after treatment, a study (Johnstone 1981a) which examined the effects of various spacings on the development of dense, fire-origin stands of 7-year-old lodgepole pine.

### METHODS

#### Site Selection and Study Establishment

The study was established in an area known locally as the Gregg Burn, which is located just south of Hinton, Alberta ( $53^{\circ}25' N$ ,  $117^{\circ}34' W$ ). This area is classified as the Upper Foothills Section (classification: B. 19c) of the Boreal Forest Region (Rowe 1972). Three sites, judged to be of low, intermediate, and high productivity, were chosen within pure, even-aged stands of 7-year-old lodgepole pine which regenerated naturally following a 1956 wildfire. Detailed descriptions of these sites are reported by Johnstone (1981a).

The experimental design and methods of establishment are described in detail by Johnstone (1981a). Briefly, five spacing levels or levels of growing stock (LGS) were established on variable-area plots, containing 100 treatment trees per plot (table

1), during the fall of 1963 and the spring of 1964. A square ( $10 \times 10$ ) grid was established on each plot, and all trees except the healthiest and most vigorous tree within 46 cm (18 in.) of each grid intersection were removed. Grid distances and variable plot size are shown in table 1. Two blocks, each containing the five spacings, were established on each site. Therefore, the study is based on 3000 treatment trees from three sites, each containing two blocks of five plots each.

#### Measurement, Compilation, and Analysis

In the fall of 1964, after the first growing season following spacing, and in the fall of 1966, the total height was measured and recorded for all treatment trees. The diameter at breast height, total height, crown width, and crown length of each tree were measured in the falls of 1971, 1976, and 1981. Damage to treatment trees caused by insects, diseases, or animals was also recorded. All invading conifers were removed from the plots in 1971.

All measurements were performed in Canadian yard/pound units and these values were subsequently converted to the Système International d'Unités (SI) using Bowen's (1974) recommended conversion factors. Breast-height measurements were taken at 1.37 m (4.5 ft.). The total volume of each tree was calculated from the following equations<sup>1</sup>:

1. Trees  $\leq 8.9$  cm ( $\leq 3.5$  in.) dbhob:

$$V = 0.0232 + 0.00253 D^2 H$$

2. Trees 9.1-21.6 cm (3.6-8.5 in.) dbhob:

$$V = -0.0949 + 0.00272 D^2 H$$

where V = volume in cubic feet (stump and top included, bark excluded)

D = diameter at breast height outside bark (dbhob)  
in inches

H = total height in feet

<sup>1</sup> Kirby, C. L. Unpublished file report on tree-volume equations and volume basal-area ratios for white spruce and lodgepole pine in Alberta, 1973. Northern Forest Research Centre, Canadian Forestry Service, Edmonton, Alberta.

Table 1--Spacing, grid intervals, and variable plot size for the treatment plots.

Levels of growing stock (LGS)	Spacing		Grid interval		Plot size	
	Trees/ha	Trees/acre	m	ft	ha	acre
1	494	200	4.50	14.76	0.200	0.500
2	988	400	3.18	10.44	0.101	0.250
3	1977	800	2.25	7.38	0.051	0.125
4	3954	1600	1.59	5.22	0.025	0.063
5	7907	3200	1.12	3.69	0.013	0.031

Merchantable volumes, based upon a 10.16-cm (4.0-in.) diameter inside bark top and a 0.30-m (1.0-ft.) stump, were calculated for all trees  $\geq 11.68$  cm ( $\geq 4.6$  in.) dbhob using Honer's (1967) merchantable conversion function for lodgepole pine.

In lieu of the presence of a similarly treated buffer zone, the analyses were based on the 64 inner sample trees in each plot (*i.e.*, the 36 perimetrical trees were eliminated from analysis). Average and per-hectare stand values of each plot were analyzed for each measurement period. Per-hectare values are net values (*i.e.*, exclude mortality) and were determined for each plot by multiplying the mean value of the sample trees (volume, basal area, or crown area) times the spacing level times the number of live sample trees as a decimal fraction of 64. In these calculations, the tree crowns were assumed to be circular in shape. The following randomized complete-block analysis of variance was used for all average and per-hectare value comparisons:

Source	Degrees of freedom
Sites (S)	2
Spacing (T)	4
Site x spacing (S x T)	8
Block within site (B wi S)	3
Spacing x block within site (T x B wi S)	12
Total	29

Table 2--Effects of site and spacing on lodgepole pine stand development, and a comparison of treatment effects.

Characteristics	Source of variation <sup>1</sup>	Statistical significance <sup>2</sup>	Level of growing stock <sup>3</sup>
Mean height (Age 25)	S T	** *	5 <u>4</u> <u>3</u> <u>2</u> <u>1</u>
Mean periodic height growth (Age 20-25)	S T	*	5 <u>4</u> <u>1</u> <u>3</u> <u>2</u>
Mean dbhob (Age 25)	S T	** **	5 <u>4</u> <u>3</u> <u>2</u> <u>1</u>
Mean periodic dbhob growth (Age 20-25)	S T	*	5 <u>4</u> <u>3</u> <u>2</u> <u>1</u>
Crown width (Age 25)	S T	** **	5 <u>4</u> <u>3</u> <u>2</u> <u>1</u>
Crown closure (Age 25)	S T	** **	1 <u>2</u> <u>3</u> <u>4</u> <u>5</u>
Percent live crown length (Age 25)	S T	** **	5 <u>4</u> <u>3</u> <u>2</u> <u>1</u>
Basal area (Age 25)	S T	** **	1 <u>2</u> <u>3</u> <u>4</u> <u>5</u>
Mean total volume/tree (Age 25)	S T	** **	5 <u>4</u> <u>3</u> <u>2</u> <u>1</u>
Net total volume/ha (Age 25)	S T	** **	1 <u>2</u> <u>3</u> <u>4</u> <u>5</u>
Net merchantable volume/ha (Age 25)	S T	** *	5 <u>4</u> <u>3</u> <u>1</u> <u>2</u>

<sup>1</sup>S = site; T = treatment (spacing).

<sup>2</sup>\* significant at  $p = 0.05$  level; \*\* significant at  $p = 0.01$  level.

<sup>3</sup>Treatments are arranged in ascending order of means. Treatments underscored by the same line are not significantly different at  $p = 0.05$ .

Treatment means were compared using Duncan's new multiple-range test. In addition, an analysis of covariance (Zar 1974) of 1981 data, was used to determine the effect of spacing on the parabolic relationship between height and diameter over the range of sites.

## RESULTS AND DISCUSSION

Data from both blocks in each site were combined for ease of presentation in this report. This was done despite significant differences in crown width and crown closure between the blocks within each productivity site. For the first time in this experiment, significant differences between blocks within sites were also observed for periodic height growth and periodic diameter growth. These differences between blocks within sites may indicate that the catastrophic mortality, which will be discussed in a later section, is beginning to compromise individual treatment responses within the overall experiment. The effects of site and spacing on growth and yield are summarized in table 2 along with detailed comparisons of treatment means. No significant site x spacing interactions were observed 18 years after treatment, indicating that site productivity was not modifying the response to spacing. In all cases, both site and spacing have significantly affected these characteristics.

## Height

Spacing had a significant effect on mean stand height of the 25-year-old lodgepole pine (table 2) particularly on the low and intermediate sites (fig. 1). Johnstone (1981a) previously speculated that this may reflect more-intense competition for moisture and nutrients on these lower sites. Note that, on the high site, the greatest mean height continues to occur at LGS 2, and the mean height of LGS 1 is now ranked second lowest of the five spacing levels. During the past five years, LGS 5 grew significantly slower than the remaining treatments (table 2), and, on the highest site, the slowest growth was observed at LGS 1 and LGS 5 (fig. 1).

Analyses of covariance detected no between-block differences in the height-diameter relationship, within each site, for each spacing. Consequently, data from both blocks within each site were combined for each treatment. Differences in the intercepts resulted in significant overall between-treatment differences on the high site even though there were no differences in the slopes of the relationships. Equations for LGS 1 and LGS 5 were not parallel on the intermediate site, giving significant overall differences between spacings when combined with differences in intercepts. On the low site, differences in intercepts, plus differences in the slopes of LGS 3, 4, and 5, resulted in significant

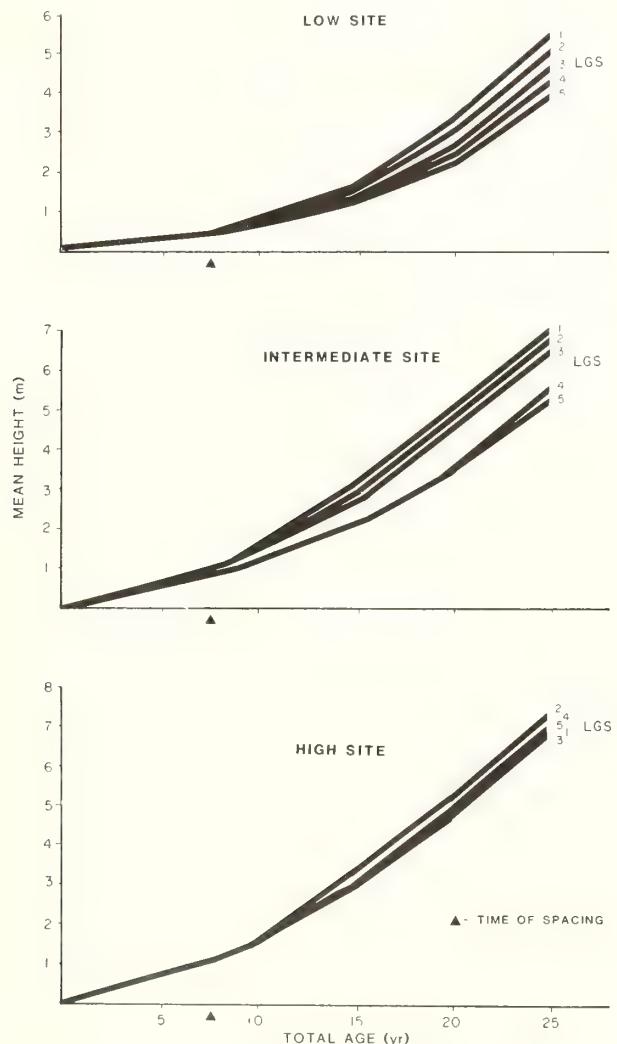


Figure 1.--Height development of spaced lodgepole pine.

differences between spacings in the height-diameter equations. For a given diameter, tree height was inversely related to degree of spacing (*i.e.*, the wider the spacing, the shorter the tree). Although these differences were consistent for all sites, the magnitude of the differences varied directly with site productivity (*i.e.*, differences between spacings on the high site were substantially larger than differences between corresponding spacings on the low site). There also appears to be a trend toward slightly taller trees, for a given diameter, on the high site than on the low site.

## Diameter

Spacing continues to have a significant and dramatic effect on diameter development on all sites (fig. 2) in that the mean diameter and diameter increment are directly related to

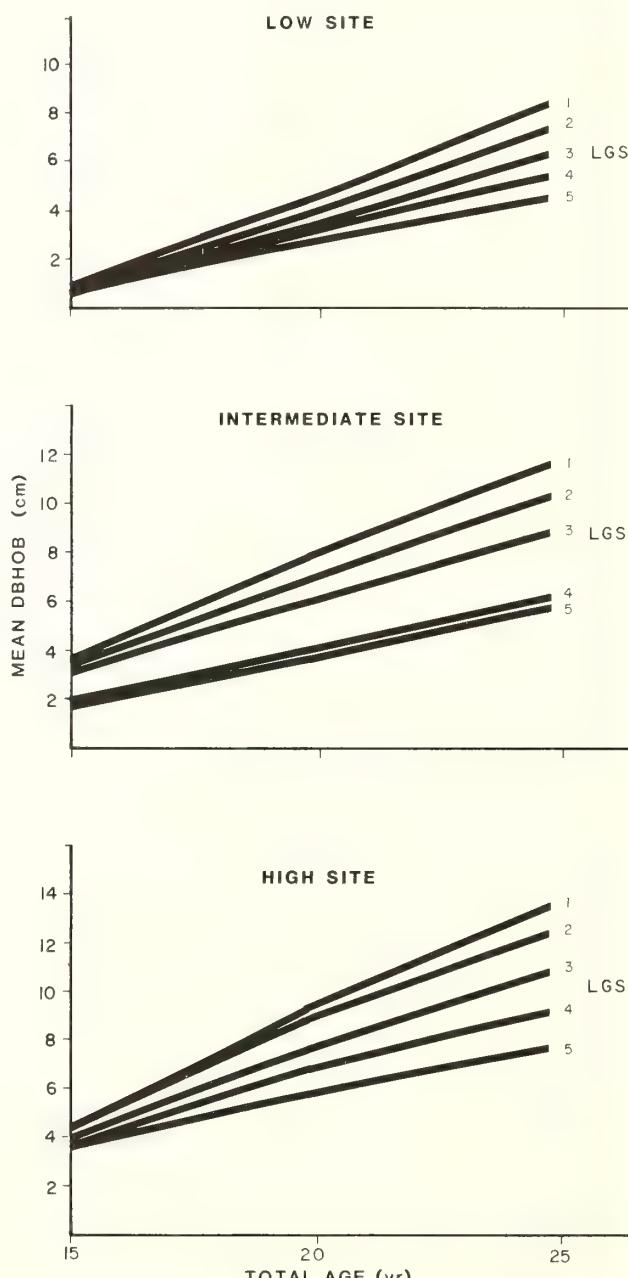


Figure 2.--Diameter development of lodgepole pine.

amount of growing space. The mean diameters at LGS 4 and LGS 5 were smaller than the remaining spacing levels, and mean diameter increment increased significantly with each increase in spacing (table 2). The previous analysis (Johnstone 1981a) showed a significant site x spacing interaction in periodic (from ages 15 to 20 years) diameter growth, which reflected a more rapid decline in growth with respect to spacing on the high site compared to the lower sites. No significant site x spacing interaction was observed from ages 20 to 25 indicating that there is no longer a differential diameter growth response to spacing on the various sites.

#### Crown Development

Site and spacing had significant effects on crown expansion and crown width (table 2 and fig. 3). Trees on the best site and at the widest spacings exhibited the widest crowns, and trees on

the poorest site and at the closest spacing had the narrowest crowns. Consequently, the rate of crown closure is directly related to site productivity for a given level of growing stock (fig. 4). The crowns have fully closed (crown closure of 123%) and overlap by about 11% at LGS 5 on the high site. Both site and spacing also had a significant effect on the proportion of the bole supporting the live crown (table 2). The relative rate of crown lift is faster on the higher sites and at the closer spacings (fig. 5, over). Rate of crown lift is presumably directly related to rate of crown closure.

#### Basal Area and Volume

Wider spacing resulted in significantly lower basal areas and total stand volumes at 25 years of age (table 2) despite signifi-

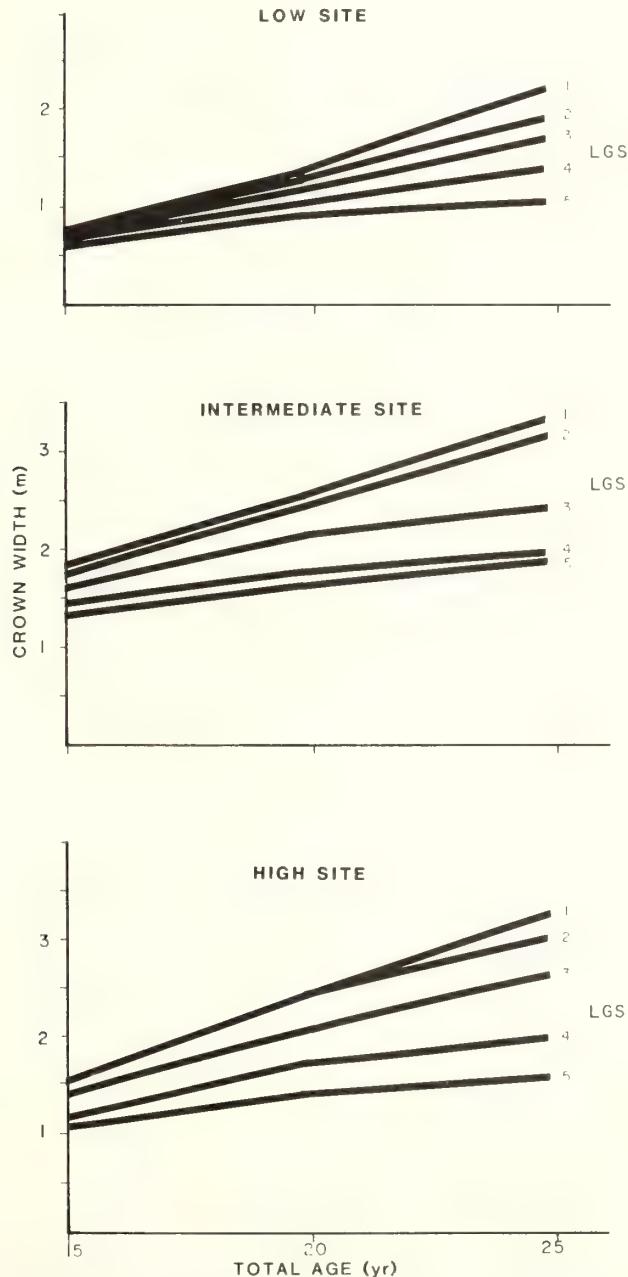


Figure 3.--Crown-width development of spaced lodgepole pine.

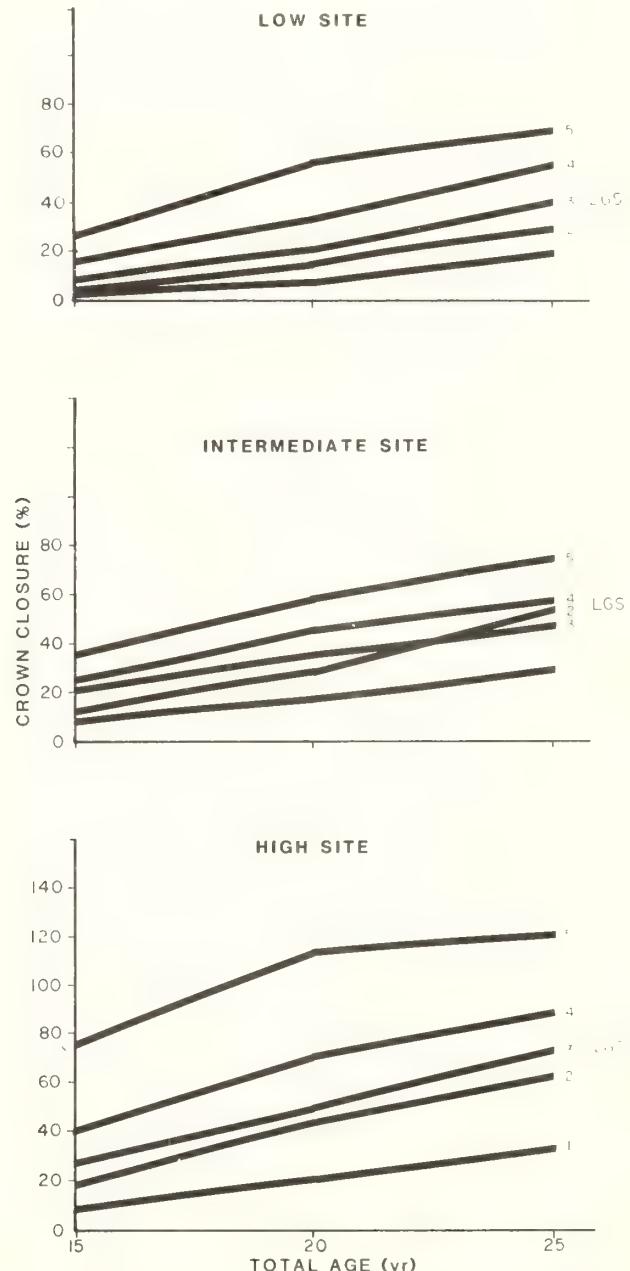


Figure 4.--Effect of spacing on crown closure of spaced lodgepole pine.

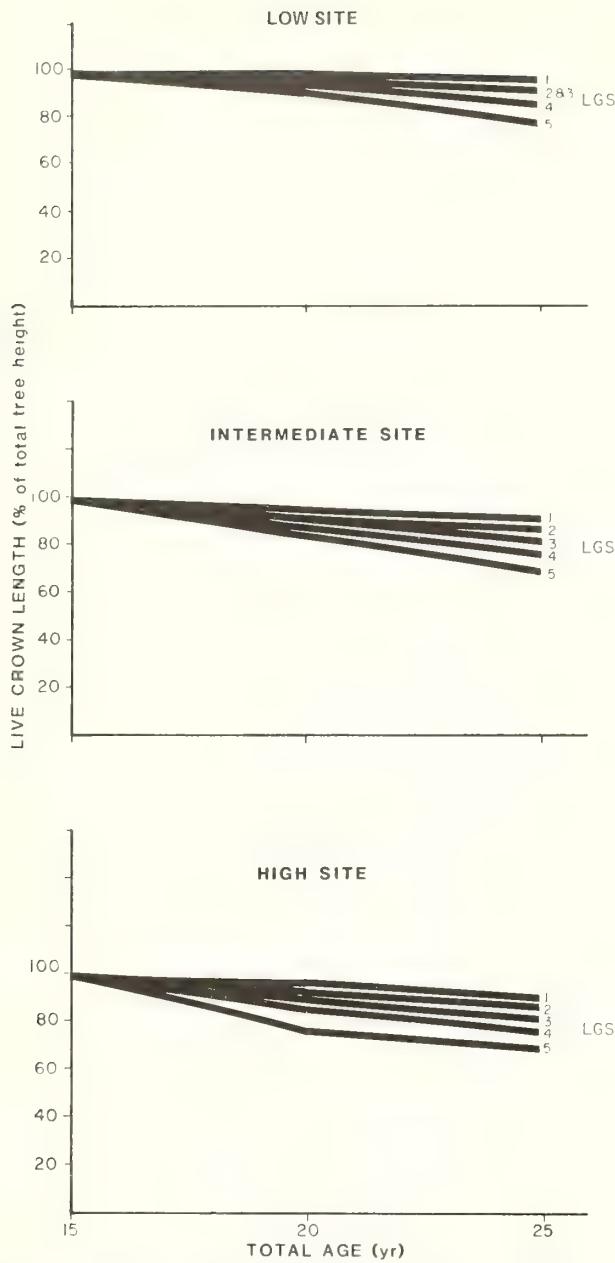


Figure 5.--Effect of spacing on the crown length of lodgepole pine.

cantly larger (fig. 6) and faster growing trees, because of the disproportionately greater number of stems at the closer spacing. Several important yield trends are developing (fig. 7), although it is still uncertain whether the wider spacings will ever achieve the same total volume production of the close spacings. Averaged over all sites, the difference in total volume per tree at LGS 1 compared to LGS 5 has increased during the past 10 years from 195% to 344%, while the difference in total volume per hectare has declined from 814% to 304%. It is probable that this gap in net total volume production will continue to decline when mortality resulting from intertree competition becomes more severe at the closer spacings.

The production of merchantable (pulpwood) volume was also significantly affected by both site and spacing (table 2). Except on the poorest site, where merchantable volume is essentially negligible, LGS 2 produced the highest pulpwood yield at 25

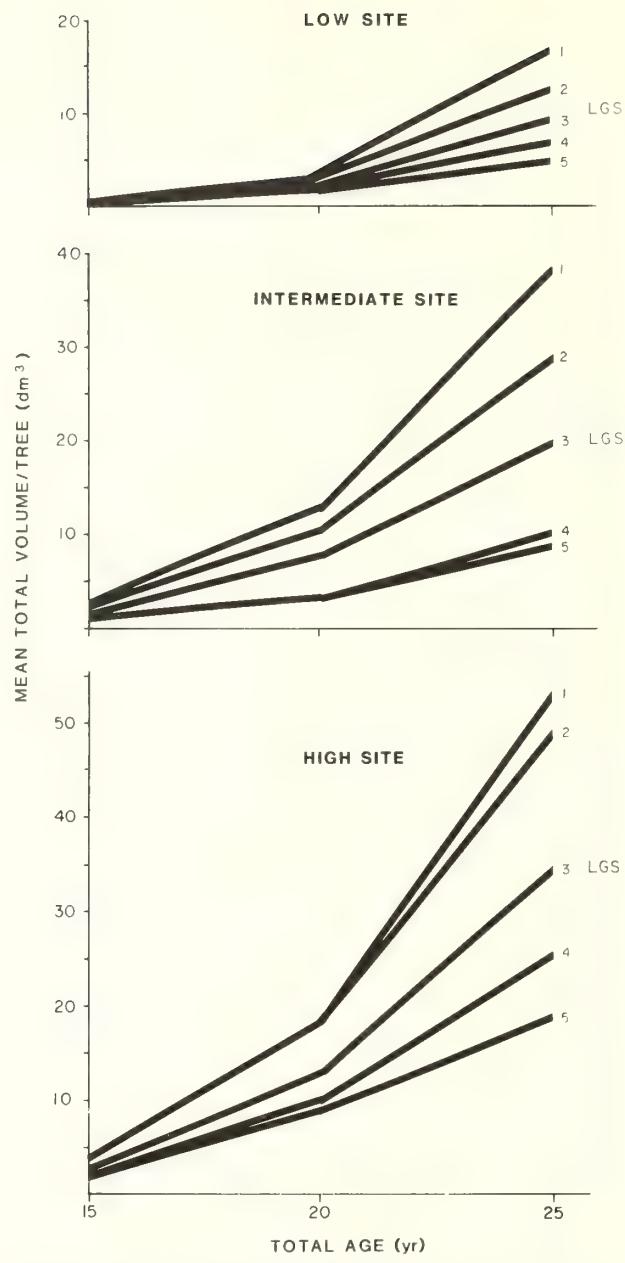


Figure 6.--Effect of spacing on total volume per tree of lodgepole pine.

years of age (fig. 8). LGS 2 and LGS 3 have surpassed the merchantable volume per hectare of LGS 1 on the high site because substantially more (85% and 66%, respectively) trees achieved merchantable size. Furthermore, height growth at LGS 1 is slower. It is likely that LGS 2 and LGS 3 will continue to produce higher pulpwood yields than LGS 1, particularly on the high site, because more trees are currently approaching the merchantability-size threshold at LGS 2 and LGS 3 than at LGS 1.

#### Mortality

Mortality, which varied on an individual-plot basis from 0% to 66%, is of real concern in this study. The two main causes of mortality (Johnstone 1981a) are shoe-string root rot (*Armillaria mellea* (Vahl. ex Fr.) Kummer) and small-mammal girdling

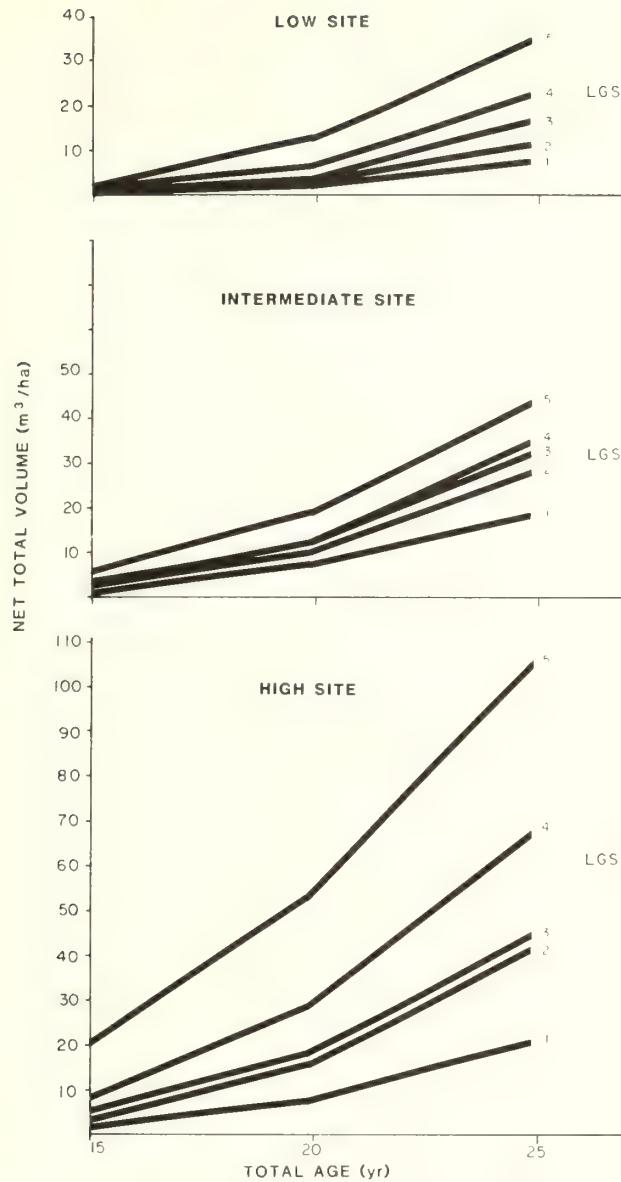


Figure 7.--Total volume-per-hectare development of spaced lodgepole pine.

(i.e., snowshoe hares, *Lepus americanus*, and red squirrels, *Tamiasciurus hudsonicus*). Damage and mortality are localized within the experiment, thus resulting in the significant differences among blocks within sites. An analysis of variance indicated that mortality was not related to spacing, but was significantly higher on the most productive site than on the low site. A large proportion of the sample trees have also been infected by western gall rust (*Endocronartium harknessii* (J. P. Moore) Y. Hiratsuka), which not only reduces tree growth and quality, but which also increases the risk of snow or wind breakage.

#### CONCLUSIONS

Natural lodgepole pine stands in west-central Alberta are frequently too dense to produce merchantable yields in keeping with the productive capacity of the sites on which they grow. Excessive stand density also increases the rate and amount of mortality, the length of rotation, and harvesting cost. Juvenile spacing can drastically alter stand growth and yield, and is a

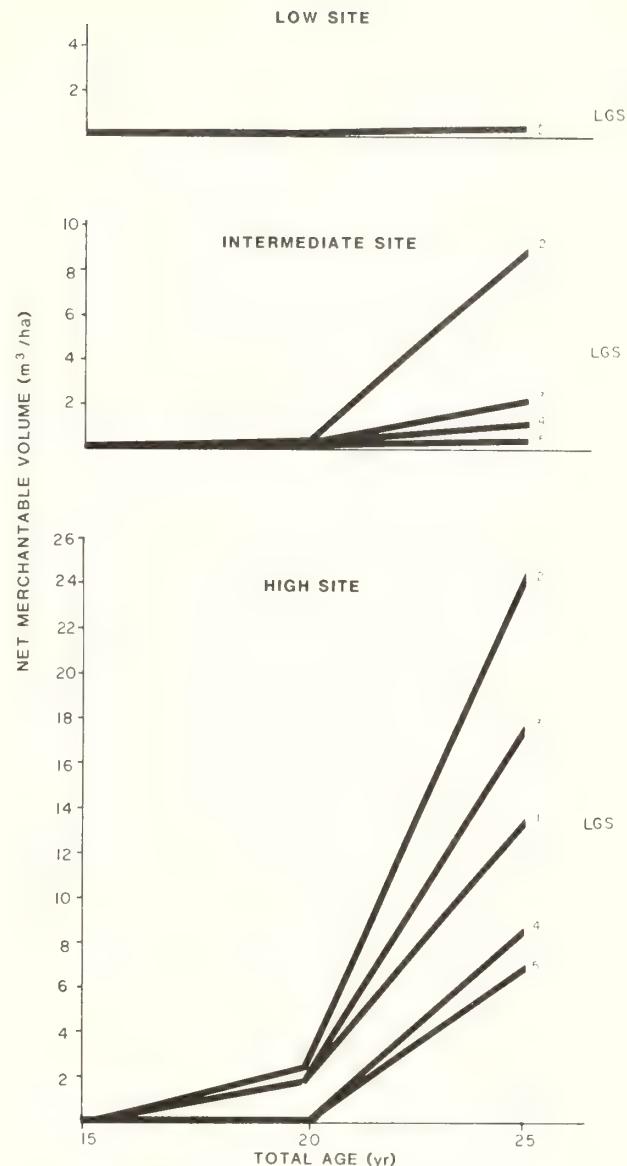


Figure 8.--Merchantable volume-per-hectare development of spaced lodgepole pine.

valuable silvicultural tool for remedying many of the problems associated with densely regenerated lodgepole pine. This study continues to provide the biological-response data required to identify optimum management regimes for lodgepole pine.

The dramatic effects of spacing on average stand diameter and diameter increment are consistent with earlier studies of the species. The mean diameter and recent diameter growth of LGS 1 increased by 89% and 131%, respectively, relative to LGS 5 when averaged over all sites. These differences have increased since last reported at age 20 (Johnstone 1981a). Diameter growth response to selective thinning, such as is studied here, will undoubtedly exceed the response to mechanical strip thinning (Bella and De Franceschi 1982), because those trees most likely to respond favorably can be retained for future crop trees.

The effects of spacing on average height and height growth were less dramatic and less conclusive than on diameter, except on the low and intermediate sites. The widest spacing on the best site may even have reduced height growth. Trees at the widest

spacing on the high site may be expanding their crowns so rapidly that diameter increment accelerates at the expense of height growth. This hypothesis is supported by analyses of the height-diameter relationship. Trees grown at wider spacings were shorter than trees grown at closer spacings for a given diameter class. Consequently, bole taper will increase with increases in spacing, and both the total volume and the sawmill recovery by diameter class will be reduced. It is fortunate that this effect of spacing is less pronounced on poorer sites, because wider spacing appears to be more advantageous on low sites compared to high sites. These results support other studies (Alexander 1960; Johnstone 1981b, 1982) which indicate that lodgepole pine requires a limited degree of crowding to maximize height growth.

This study demonstrates the need for forest managers to clearly identify and define their future timber objectives, preferably on a site-specific basis. Despite significantly larger and faster-growing trees, both total volume and total volume growth were significantly lower at the widest spacing. At the same time, the largest merchantable yield did not occur at the widest spacing. At the same time, the largest merchantable yield did not occur at the widest spacing. Consequently, although wide spacing may shorten technical rotation lengths (*i.e.*, the time required to grow trees of a desired size), wide spacing may also reduce total stand productivity. Obviously, some method of optimizing individual tree growth with levels of growing stock is warranted to maximize the yield of desired products on an area basis. The practice of increasing the current allowable annual cut of mature timber in proportion to the anticipated improvement of future volume yields is often used as an incentive to encourage more intensive forest management. In order to ensure the continuity of future harvests, this method of apportionment should only be applied after the productive capacities of the sites to be managed have been duly considered. With respect to the stand-density management of natural lodgepole pine, the present study shows that the largest relative gains occur on poorer sites but that the actual absolute gains on these sites may be negligible.

Because of the high mortality losses caused by biotic agents in this study and by climatic factors in other studies (*i.e.*, Johnstone 1982), there is an urgent need for a comprehensive evaluation and study of the risks and uncertainties associated with the management of natural lodgepole pine stands. Quantitative risk factors developed from such a study should be incorporated into planning models and stand-management regimes. Continued remeasurement and analysis of the present study will continue to contribute to the understanding of the management of natural lodgepole pine stands in west-central Alberta and elsewhere.

#### ACKNOWLEDGMENTS

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#### LITERATURE CITED

- Alexander, R. R. Two methods of thinning young lodgepole pine in the central Rocky Mountains. *J. For.* 54(2): 99-102; 1956.
- . Thinning lodgepole pine in the central Rocky Mountains. *J. For.* 58(2): 99-104; 1960.
- . Growth of thinned young lodgepole pine in Colorado. *J. For.* 63(6): 429-433; 1965.
- Barrett, J. W. Response of 55-year-old lodgepole pine to thinning. *Res. Note 206. U. S. For. Serv., Pac. Northwest For. Range Exp. Stn.*; 1961.
- Bella, I. E.; De Franceschi, J. P. Growth of lodgepole pine after mechanical strip thinning in Alberta: 15-year results. *For. Chron.* 58(3): 131-135; 1982.
- Bowen, M. G. Selected metric (SI) units and conversions factors for Canadian forestry. Metric Commission Canada, Section Committee 8.1, Forestry. *Environ. Can., Can. For. Serv., Ottawa, Ont: For. Manage. Inst.*; 1974.
- Cole, D. M. Culture of immature lodgepole pine stands for timber objectives. In: Baumgartner, D. M., ed. *Management of lodgepole pine ecosystems. Vol. 2. Pullman, Wash: Wash. State Univ.*; 1975: 536-555.
- Dahms, W. G. Low stand density speeds lodgepole pine tree growth. *Res. Note PNW-47. U. S. For. Serv.*; 1967.
- . Growth response in lodgepole pine following precommercial thinning. In: *Precommercial thinning of coastal and intermountain forests in the Pacific Northwest; Pullman, Wash: Wash. State Univ.*; 1971a: 14-18.
- . Fifty-five-year-old lodgepole pine responds to thinnings. *Res. Note PNW-141. U. S. For. Serv.*; 1971b.
- . Growth and soil moisture in thinned lodgepole pine. *Res. Pap. PNW-127. U. S. For. Serv.*; 1971c.
- . Tree growth and water use response to thinning in a 47-year-old lodgepole pine stand. *Res. Note PNW-194. U. S. For. Serv.*; 1973.
- Daniel, T. W.; Barnes, G. H. Thinning a young stand of lodgepole pine. *Soc. Am. For. Proc.* 1959: 159-163; 1958.
- Johnstone, W. D. Variable-density yield tables for natural stands of lodgepole pine in Alberta. *Tech. Rep. 20. Can. Dep. Fish. Environ., Can. For. Serv. For.*; 1976.
- . Effects of spacing 7-year-old lodgepole pine in west-central Alberta. *Inf. Rep. NOR-X-236. Edmonton, Alberta: Environ. Can., Can. For. Serv., North. For. Res. Cent.*; 1981a.
- . Precommercial thinning speeds growth and development of lodgepole pine: 25-year results. *Inf. Rep. NOR-X-237. Edmonton, Alberta: Environ. Can., For. Serv., North. For. Res. Cent.*; 1981b.
- . Juvenile spacing of 25-year-old lodgepole pine in western Alberta. *Inf. Rep. NOR-X-244. Edmonton, Alberta: Environ. Can., Can. For. Serv., North. For. Res. Cent.*; 1982.
- Rowe, J. S. Forest regions of Canada. *Publ. 1300. Environ. Can., Can. For. Serv.*; 1972.
- Smithers, L. A. Thinning in lodgepole pine stands in Alberta. *Div. Tech Note 52. Can. Dep. North. Aff. Nat. Resour., For Branch, For. Res.*; 1957.
- . Lodgepole pine in Alberta. *Can. Dep. North. Aff. Nat. Resour., For. Branch, For. Bull. 127.*; 1961.
- Zar, J. H. *Biostatistical Analysis*. Englewood Cliffs, N. J.: Prentice-Hall, Inc.; 1974.

## NATURAL LODGEPOLE PINE IN WEST-CENTRAL ALBERTA

### PART III: FERTILIZATION

Richard Yang

#### INTRODUCTION

Along with regeneration stocking control and juvenile spacing, fertilization provides a further opportunity for foresters to increase site and stand productivities. Although the actual acreage of commercial forest land fertilized in Canada is small, many research studies have been established by federal and provincial agencies as well as by industry (Rennie 1974). Little information is currently available, however, on effects of fertilization on growth and yield of lodgepole pine in Alberta.

Forest fertilization involves an investment in forest stands and sites. Information on the kind, quantity, and time of application of fertilizers needed to produce the best return is required before a sound decision can be made. This section reports preliminary analysis on the effects of N, P, and S fertilizers on a preharvest, 70-year-old lodgepole pine stand. Fertilization of preharvest stands is of great interest to forest managers since there is a possibility that investment costs plus interest can be more than recouped in a short period by increased yields.

#### METHODS AND MATERIALS

##### Study Area

Four study areas were selected in 1970 on St. Regis (Alberta) Ltd. (formerly the Northwestern Pulp and Power Company) lands near Hinton, Alberta. The study areas were located with normal density stands of two stand ages (30 and 70 years old) on Coalspur (Orthic Gray Luvisol) and Mercoal (Bisequal Gray Luvisol) soil types. Results from the 70-year-old lodgepole pine stand on the Coalspur soil type are reported here.

The study area was divided into three blocks, each of which contained twenty-four plots as required by the experimental design. The plot centers were established systematically on a

square grid at about 30-m (15-chain) intervals. When a plot center fell within an abnormally open portion of the stand, the plot was omitted or moved to an adjacent fully stocked portion of the stand. Circular plots (8.0-m radius) of 1/50 hectare (1/20 acre) were used. Each plot center was marked with an aluminum post bearing the plot number, and ten unsuppressed trees closest to the plot center were tagged 15 cm above breast height. The diameter at breast height outside bark (dbhob) of all living trees in each plot and sufficient heights to form a reliable height-diameter relationship were taken in the fall of 1971.

##### Experimental Design

The central-composite, rotatable, second-order design (Cochran and Cox 1957) was selected for the study because the primary objective of the study has been to develop a general, predictive relationship between tree and stand responses and the incremental addition of fertilizer. Fourteen treatment combinations plus six repeating central treatments are required for three factors with five levels of fertilizer (fig. 1). Table 1 illustrates the five coded fertilizer levels being tested and the actual rates of N, P, and S on a hectare basis.

Table 2 presents the treatment combinations included in this study. In addition to the twenty composite design treatments (treatments 1-20), four combinations (treatments 21-24) were also incorporated to facilitate the analysis of an additional  $2^3$  factorial (-1.68 and 0 levels). The twenty-four treatments were randomly assigned to plots within a block.

Nutrient sources and their composition are listed in table 3. Nitrogen-free treatments were made using the required quantities of triple superphosphate, and elemental sulfur and phosphorus-free treatments were prepared by combining the required quantities of urea and sulfur. To minimize the contamination of the sulfur-free treatments by phosphorus ammonium phosphate was used whenever possible.

The fertilizer combination for each plot was precisely weighed out, bagged, and identified by plot number in the laboratory prior to the field application. All of the fertilizer treatments were broadcast using cyclone seeders prior to the 1972 growing season.

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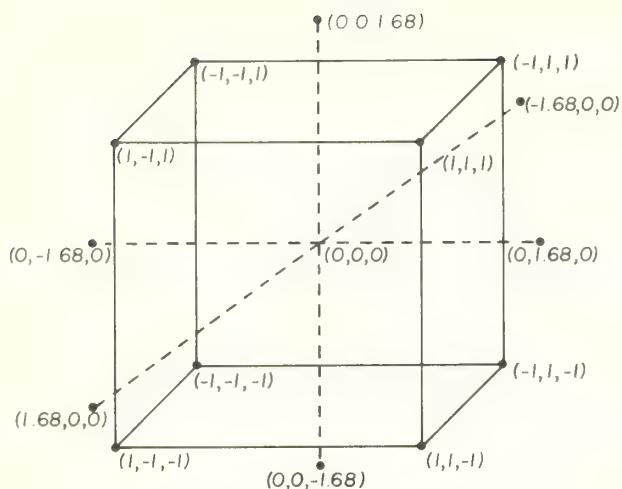


Figure 1.--Graphical representation of a 3-factor central composite rotatable design.

Table 1--Amount of N, P, and S elements applied

Code level	Amount of elements (kg/ha)		
	N	P	S
-1.68	376	188	113
1	300	150	91
0	188	94	56
-1	76	38	23
-1.68	0	0	0

Table 2--Combinations of fertilizer treatments applied

Treatment No.	Code amount of element		
	N	P	S
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1
9	-1.68	0	0
10	1.68	0	0
11	0	-1.68	0
12	0	1.68	0
13	0	0	-1.68
14	0	0	1.68
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	-1.68	-1.68
22	-1.68	0	-1.68
23	-1.68	-1.68	0
24	-1.68	-1.68	-1.68

#### Data Compilation and Analysis

After ten growing seasons, the plots were remeasured in the summer of 1981 to determine the fertilization effects on individual tree and stand growth. All living trees in each plot were identified by species and dbh was tallied. For accurate determination of individual tree-volume increment due to various fertilizer treatments, three dominant or codominant trees in each plot were felled for stem analysis. Disks were obtained at 0.3-m stump, breast height, 3.05-m, live crown, and other height positions where a major bole shape change was taking place.

Periodic dbh increment was determined by the diameter at breast height of the ten tagged trees with two successive measurements. Tree dbh data were excluded from the analysis whenever a tagged tree was found dead or missing in the remeasurement. Individual tree-volume increments were ascertained from volumes of the three sectioned dominant or codominant trees.

Stand-volume increments during the ten growing seasons were obtained by deriving an average diameter-height curve for trees of the study area and by using the volume equations for lodgepole pine which were described in Part II: Juvenile Spacing. Merchantable volumes, based on a 10.16-cm (4.0-in.) diameter inside bark (dib) top and a 0.30-m (1.0-ft.) stump, were calculated for all trees >11.68 cm (>4.6 in.) dbh using Honer's (1967) merchantable conversion function for lodgepole pine. All measurements were performed in imperial units and subsequently converted into the SI system.

Efforts were made to analyze the compiled data by the central-composite, rotatable, second-order design by fitting the data to the second-degree polynomial function. The equation, however, accounted for only 30-40% of the variation in the response variables. In all cases, the lack of fit term which determines the adequacy of the equation was highly significant.

The data were subsequently analyzed by the two subfactorials incorporated in the design and randomized, complete-block arrangement of treatments. The analysis of covariance with individual tree dbh, volume, or basal area per hectare prior to fertilization as a covariate was employed.

#### RESULTS AND DISCUSSION

Adjusted treatment means of response variables showing 10-year periodic growth increments are summarized in table 4. The mean dbh and volume increments are respectively adjusted for average tree dbh or volume for each treatment prior to fertilization, whereas stand-response variables are adjusted for basal area per hectare of respective treatments. The analyses of covariance were justified and necessary to compare the fertilization effects of the same basis.

It was generally observed in the field that the effects of fertilizer on tree and stand growth are influenced not only by stand

Table 3--Nutrient sources and their chemical composition

Nutrient sources	Composition	Elemental composition
Urea (46-0-0)	46% N	46% N
Ammonium phosphate (11-55-0)	11% N 55% $P_2O_5$	11% N 24% P trace S
Tri. super-phosphate (0-45-0)	45% $P_2O_5$	19.7% P 0.9% S
Elemental sulfur	100% S	100% S

density but, to a certain extent by topographical characteristics such as slope position and soil depth as well. Growth responses of the preharvest lodgepole pine are usually more pronounced for trees grown on low, concave surfaces than for those on high, concave ones. Nutrient movement and soil erosion probably explain to a large extent the variation in tree-growth responses.

#### Individual Tree dbh Increment

Although some fertilizer treatments produced a substantial increase in dbh growth in the 10-year period (fig. 2), the periodic increments in dbh of the ten tagged trees were not significantly different from that of the unfertilized control

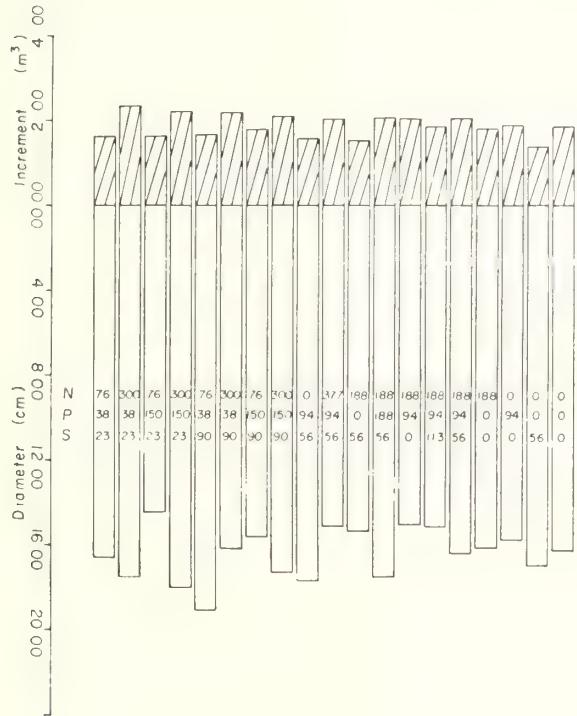


Figure 2.--Tree dbh increments in response to N, P, and S fertilization (kg/ha).

plots, due primarily to a large variation among trees within treatments. As a result of intertree competition in the pre-harvest, lodgepole pine stand, some of the ten tagged trees became unavoidably suppressed by the others after 10 years of dynamic development. While trees in dominating positions showed substantial increases in dbh growth in response to a fertilizer treatment, the suppressed trees produced little growth.

It is also noted that the periodic dbh increment is significantly poorer in some treatments (*e.g.*, treatments 5, 9, and 23) than that of the control. These plots were treated with medium to high rates of S (0 to 1 level) and mixed with a nil to low (-1.68 to -1) level of N. Luvisol is reportedly deficient in sulfur, nevertheless, the results seem to indicate that, in the absence of N, excessive sulfur could adversely affect the dbh growth in the preharvest lodgepole stand.

Figure 3 illustrates dbh increments in response to five incremental additions of N, P, and S. Apparently, N is required in large quantities for dbh growth because the dbh increment increased with an incremental addition of N in the range tested. The growth response showed quadratic trends to added P with a maximum growth at the 0 level of P (94 kg/ha). On the other

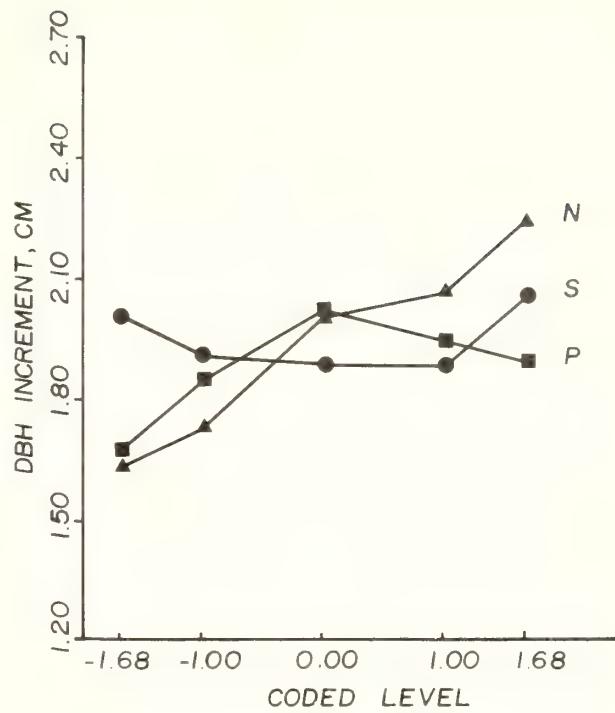


Figure 3.--Periodic dbh growth increment in response to 5 levels of N, P, and S fertilization.

hand, the dbh growth responded negatively to the addition of S to the 1 level; the reduction in dbh growth, however, is not significant.

#### Individual Tree-Volume Growth

Figure 4 shows the average tree-volume increments and tree volumes for treatments before the application of fertilizers. For dominant or codominant trees in the unfertilized control plots,

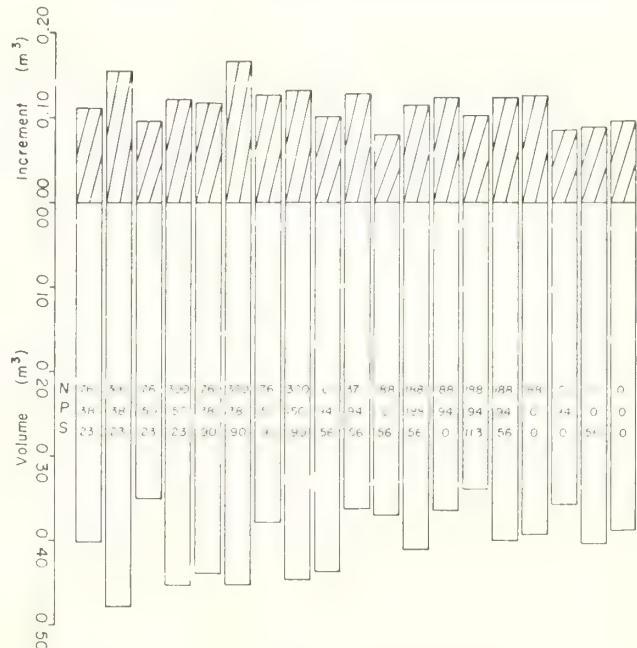


Figure 4.--Periodic tree volume growth in response to N, P, and S fertilization (kg/ha).

volume increment averaged  $0.095 \text{ m}^3$  in the 10-year period. The volume increment was improved 28-68% by the fertilizer treatment.

Treatments which showed a considerable periodic volume increment over the control plot are, with one exception, those with an N dosage higher than the 0 level (188 kg/ha). It appears an appreciable increment in individual tree-volume growth requires a sufficient application of N. Table 1 and figure 4 suggest that an optimum gain in the periodic tree-volume growth in the preharvest lodgepole stand is obtained with N:P ratio in the range of 2-8:1 on the Luvisol.

In the absence of N supply, the tree-volume increments seem adversely affected by the addition of either P or S alone or combined. The reduction in the tree-volume growth is statistically not significant, but it indicates that P and S should not be applied to the preharvest stand without a simultaneous application of N.

The volume-increment curves in response to incremental additions of N, P, and S remain essentially similar to those of the dbh increments (fig. 5). While the responses were linear toward added N in the range tested, they were quadratic to added P and S with a maximum increment occurring at the -1 and 1 level for P and S, respectively.

#### Stand-Growth Increments

The effects of fertilization on stand basal area, total volume, and merchantable-volume increments per hectare are less pronounced compared to those on individual tree-volume growth because of natural variation introduced during the 10-year experiment period. Mortality and, to a lesser degree, in-growth are sources of variation; some pole-size trees were found dead of natural causes in the 10-year period. Because of the variation among plots within treatments, the power of the experiment to detect the fertilization effects on stand growth is markedly reduced.

Periodic stand basal area, total volume, and merchantable-volume increments in the control are  $6.49 \text{ m}^2$ ,  $66.01 \text{ m}^3$ , and  $69.92 \text{ m}^3$  per hectare, respectively. Three fertilizer treatments

(treatments 2, 10, and 13) resulted in a significant enhancement in the periodic increments (table 4) over the control. The productivity of the preharvest stands can potentially be improved by 43-49%, 44-54%, and 45-47% for stand basal area, total volume, and merchantable volume increments, respectively, with an application of fertilizer.

The response curves for stand basal area (fig. 6), total volume (fig. 7), and merchantable-volume increments (fig. 8) per hectare are essentially identical: a linear response to added N and a quadratical response to P and S. These response curves are relatively consistent for all five response variables examined.

#### CONCLUSIONS

Based on the above results and discussion, it can be concluded that the site and stand productivities of preharvest lodgepole pine can be considerably improved by the application of fertilizer. In all tree- and stand-response variables investigated, the periodic increments responded linearly toward the incremental addition of N in the ranges tested and quadratically to the added P and S. An appreciable growth increment can occur only after a sufficient amount of N is applied. The results on the effects of P and S fertilization on the preharvest stand are less conclusive. Further studies of the effects of P and S and how they are interacting with N in lodgepole pine growth in preharvest stands are needed.

#### LITERATURE CITED

- Cochran, W. G.; Cox, G. M. Experimental designs. Second edition. New York: John Wiley and Sons, Incorporated., 1957. 611 p.
- Honer, T. G. Standard volume tables and merchantable conversion factors for the commercial tree species of Central and Eastern Canada. Inform. Rep. FMR-X-5. Ottawa, Ontario: For. Manag. Res. Serv. Inst.; 1967. 21 p.
- Rennie, P. J. Forest fertilization research in Canada. In: Proceedings of a workshop on forest fertilization in Canada held at Sault Ste. Marie, Ontario. 1974 Jan. 8-10. For. Tech. Rep. 5. Ottawa, Ontario: Canadian For. Serv. Dept. Environment; 1974.

Table 4--Adjusted treatment means of response variables showing 10-year growth increment

Treatment No.	Mean DBH increment/a/ (cm)	Mean volume increment/b/ ( $\text{m}^3$ )	Basal area increment ( $\text{m}^2/\text{ha}$ )	Total volume increment ( $\text{m}^3/\text{ha}$ )	Merchantable vol. increment ( $\text{m}^3/\text{ha}$ )
1	1.57	0.1101	5.30	57.74	59.20
2	2.15	0.1399**c/	9.70*	101.43*	101.61*
3	1.97	0.1058	7.76	79.20	81.74
4	1.93	0.1095	6.86	75.46	78.27
5	1.43*	0.1075	6.51	67.90	69.75
6	2.23	0.1608**	8.62	89.87	87.42
7	1.94	0.1343**	8.77	91.73	95.25
8	1.94	0.1227*	8.16	83.70	85.21
9	1.33*	0.0913	6.88	70.73	70.18
10	2.26	0.1394**	9.29*	99.73	102.51*
11	1.70	0.0831	6.36	63.41	65.27
12	1.88	0.1134	7.39	77.31	79.30
13	2.29	0.1338*	9.28*	94.84*	92.75
14	2.07	0.1174	6.67	71.24	76.57
15-20	2.05	0.1246**	7.81	82.01	83.81
21	1.84	0.1281**	6.46	70.06	70.29
22	2.01	0.0919	6.38	68.92	73.14
23	1.29*	0.0835	5.46	57.42	59.94
24	1.89	0.0955	6.49	66.01	69.92

a/ Based on ten tagged trees per plot;

b/ Based on three felled dominant or codominant trees;

c/ \*\*Treatment means significantly different from the control at the 1% level; \* at the 5% level.

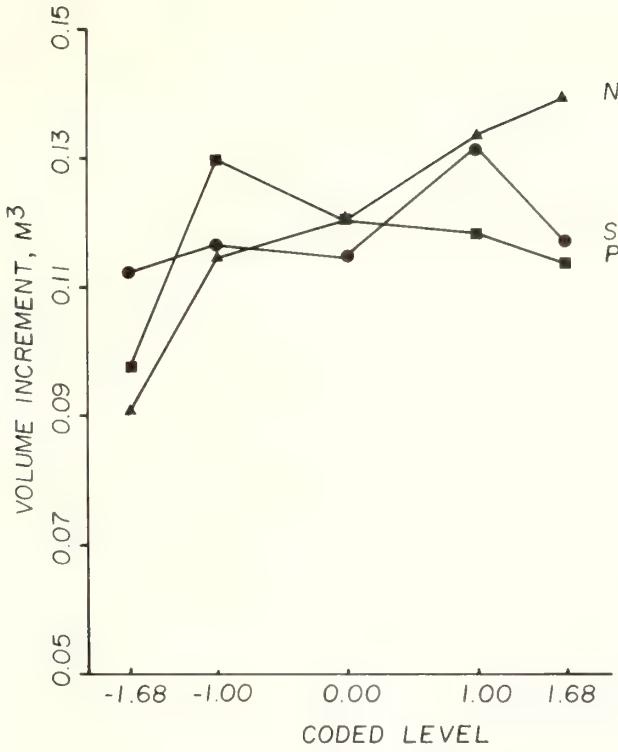


Figure 5.--Periodic tree volume growth increments in response to 5 levels of N, P, and S fertilization.

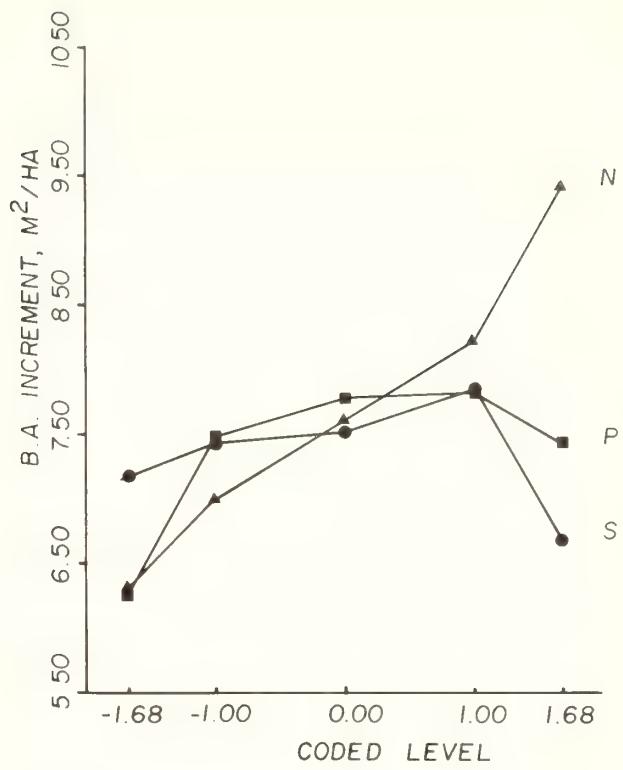


Figure 6.--Periodic basal area growth in response to 5 levels of N, P, and S fertilization.

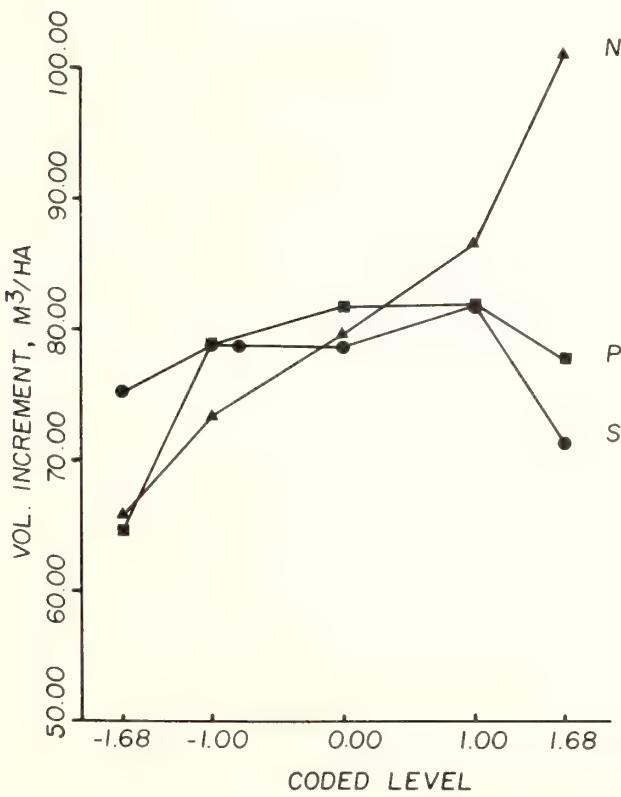


Figure 7.--Periodic total volume growth in response to 5 levels of N, P, and S fertilization.

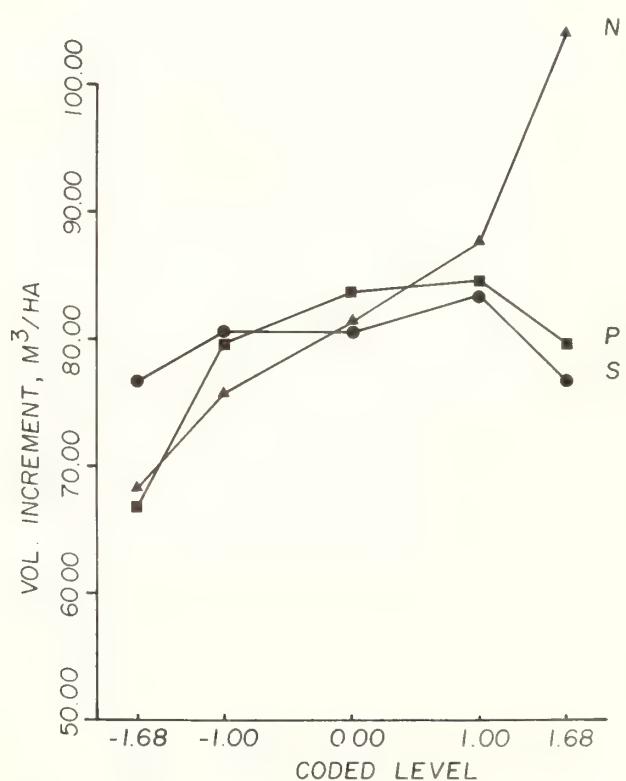


Figure 8.--Periodic merchantable volume growth in response to 5 levels of N, P, and S fertilization.

## DEVELOPMENT OF GENETICALLY IMPROVED STRAINS OF LODGEPOLE PINE SEED FOR Reforestation IN ALBERTA

Narinder K. Dhir

### INTRODUCTION

Lodgepole pine is the second most important reforestation species in Alberta. It occupies about 15 percent of the forested area in the province and accounts for approximately 35 percent of the merchantable timber inventory (McDougall 1975). Currently, approximately 6 million lodgepole pine seedlings are produced each year for forest plantings in Alberta, and this figure is expected to rise to about 10 million by 1985.

The Alberta Forest Service initiated work on genetic improvement of lodgepole pine in 1976 as part of a comprehensive forest-genetics and tree-improvement research and development program. The objective is to develop genetically superior strains of this species through selection and breeding, and to produce improved seed for production of nursery planting stock for reforestation in selected regions. The traits to be improved were specified as follows:

- a. adaptability and hardiness
- b. height and diameter growth
- c. stem form and taper
- d. crown and branching characteristics
- e. wood quality
- f. resistance to western gall rust.

### PROGRAM STRUCTURE

The most important commercial forests of lodgepole pine are found in west central Alberta. It was decided that work on genetic improvement of this species would be confined to this region, which accounts for nearly 90 percent of all lodgepole pine reforestation plantings in Alberta. For technical planning and organizing program work, the region was subdivided into four breeding regions (fig. 1), taking into consideration pertinent physiographic data, administrative boundaries of forest districts, and lease areas of various forest industries. Each breed-

ing region is covered by a separate genetic-improvement project and serves as a target area within which promising source materials are selected and tested to develop genetically superior



Figure 1--Forests and tree breeding regions of Alberta.

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strain(s) of seed which is presumed to be prescribed for reforestation only within that region.

The Alberta Forest Service is the primary agency responsible for genetic-improvement projects and related research and development in the province. The work is done jointly with forest industries on a cost- and work-shared basis. The industries participating in lodgepole pine improvement projects are:

Blue Ridge Lumber (1981) Ltd.  
British Columbia Forest Products Ltd.  
Canadian Forest Products Ltd.  
Procter and Gamble Cellulose Ltd.  
St. Regis (Alberta Ltd.)

The work is already in progress on genetic-improvement projects for breeding regions B1, B2, and C. Work on the breeding region A project is scheduled to start in 1985.

## BREEDING SCHEME

The work of a genetic-improvement project is carried out following a breeding scheme which defines strategy for realizing genetic gain through selection and breeding; the work is advanced through succeeding generations. The breeding scheme chosen for lodgepole pine improvement projects for regions B1, B2, and C is diagrammatically illustrated in figure 2. It defines the general course of the program for the first three cycles of genetic improvement. Briefly, it is described as follows:

1. Building selection population by propagating (through seed and/or scions) desirable individual trees (mass selection) located in natural stands (base population). Selection population is defined as the population on which selection is to be practiced.
2. The first cycle of improvement follows a breeding procedure referred to as *half-sib family selection*. It consists of build-

ing a selection population which consists of a collection of individual single-tree (open pollinated) seedlots. These seedlots are tested in field trials to identify a set of best seedlots. The best seedlots are retained in already established seed orchard plantations by roguing other materials. The group of trees produced by each single-tree seedlot is called a half-sib family in which individual trees are related by having a common female parent. A part of the observed variability in field performance of half-sib families is attributed to genetic causes. Therefore, superior performances of selected half-sib families retained in a seed-orchard plantation is inherited, and is fixed and capitalized upon in order to produce genetically improved seed.

3. The breeding scheme for its second cycle of improvement depends on half-sib family and half-sib progeny testing. Selection population for this cycle is partly derived from the best breeding stock identified in the screening process of the first cycle. In addition, new germplasm, derived by cross breeding a new set of parents identified to have high breeding value, is brought in to broaden the genetic base in order to sustain an appropriately high level of selection intensity.
4. The third cycle of selection and breeding is based on full-sib family selection, with selection population to be developed through appropriate mating designs employing controlled crossing of more promising breeding stock identified earlier.
5. Selection procedure, selection units (individual trees, families, etc), selection criteria, and selection intensity vary at different stages of the project. Initial emphasis of selection (mass selection in wild stands) is on selecting best trees following use of a subjective criterion (independent culling levels) which establishes sufficiently rigorous acceptance standards for various traits which a selected tree must possess. Most attention at this stage is placed on traits like form, crown, and branching characteristics. At later stages, selection is to be based on traits like height and diameter growth, wood density, and stability of performance through an objectively determined numerical score (selection index) calculated to reflect correct genetic merit of all these traits.

## CURRENT STATUS AND PROGRESS

The program for genetic improvement of lodgepole pine in Alberta is currently in its seventh year. Considerable progress has been made even though (considering the long-term nature of the program) most of the work can be characterized to be either in the planning or very early stages. A start has been made on the first cycle of genetic improvement of breeding regions B1, B2, and C projects. Progress on these to date is described below.

### Breeding Region B1

This region contains 14,800 km<sup>2</sup> and covers parts of Grande Prairie and Whitecourt Forests, plains and lower foothills areas located in the general elevation range of 800 to 1,200 m. The work is done cooperatively with B.C. Forest Products Ltd., Canadian Forest Products Ltd., and Procter and Gamble Cellulose Ltd.

The field work for selection of superior trees in the breeding region was started in 1976 and completed in 1978. The work was done jointly by all cooperators and a total of 324 selections were made by cruising forest stands located throughout the region. Selection intensity for field selection of superior trees was arbitrarily estimated to be at least 1:500. Qualifying criteria required that selected trees primarily possess: a) very good to excellent stem form; b) relatively low taper and superior natural pruning characteristics; c) desirable crown and

Figure 2.--Generalized illustration of breeding scheme.

branching characteristics; d) height superior to any dominant tree growing within a 300-m radius; e) freedom from any apparent disease, defect, or spiral grains. Cones were collected from each selected tree to provide a collection of 324 seedlots. An additional 76 seedlots collected from selected trees in the adjacent breeding region B2 were added to this collection to provide 400 seedlots for establishing half-sib family field trials and a seed orchard.

Half-sib family field trials were established in 1981 on four test sites (spread throughout the region) to determine field performance and genetic worth of individual seedlots for production of commercial seed in a seed orchard. The outplantings were done using 1-year-old container stock. The experimental design used was "blocks in reps design" which is a special case of randomized complete block design. The field design consisted of five replications per site and 4-tree row plots. The field trials will be evaluated at 5-year intervals starting in the fall of 1989 (10 years of age) to accumulate data on survival, height, and dbh. Data on wood density and fibre length will be recorded at 10-year intervals starting in the fall of 1999 (age 20). The families will be evaluated for resistance to western gall rust (*Endocronartium harknessii*) through artificial inoculation of seedling material in separate greenhouse/nursery experiments.

A farm site near Grande Prairie was recently purchased for establishing a seed orchard. The orchard will be jointly established and managed by the three cooperating forest industries, and the seed produced will be shared among the tree industries and the Alberta Forest Service. The planting of the seed orchard is expected to be completed in 1986. All 400 families will be initially outplanted in "blocks in reps design" complementary to the experimental design used in the half-sib family field trials where families are grouped into twenty-five independent sets of sixteen families each. Each set of sixteen families will be outplanted as a 4 x 4 block of single-tree family plots at 1.5m x 1.5m spacing. The orchard will be progressively thinned based on 10-, 15-, and 20-year results from half-sib family field trials in such a manner that, respectively, 4, 2, and 1 trees corresponding to the best families are retained in each 16-tree block. It is expected that after the completion of the second thinning in 1995 (based on 15 years of results from field trials), the orchard will be at a development stage where commercial collection of cones can start to provide the first crop of genetically improved seed for reforestation in 1997.

#### Breeding Region B2

This region contains 12,200 km<sup>2</sup> covering the montane and upper foothills areas of parts of Edson and Grande Prairie Forests; the general elevation range is 1,200 to 1,600 m. The work is being done cooperatively with B.C. Forest Products Ltd. and Procter and Gamble Cellulose Ltd.

The field work for selection of superior trees was completed during the 1978 and 1979. A total of 428 selections were made. Plans for establishment of half-sib family field trials and a seed orchard are expected to be finalized in the near future.

#### Breeding Region C

This region contains 5,720 km<sup>2</sup> covering the Swan Hills general area of Whitecourt and Slave Lake Forests which has an elevation range of 1,000 to 1,400 m. The work is being done cooperatively with Blue Ridge Lumber (1981) Ltd.

The field work for selection of superior trees in the breeding region was started in 1977 and completed in 1980. A total of 240 selections were made following methods and procedures as described earlier. Four half-sib family field trials were established in 1982 using blocks in reps design, and plans for measurements and evaluation of field trials are similar to those described for region B1. No firm plans have yet been made for establishment of a seed orchard. The orchard will be located near Blue Ridge, and will be established and managed by Blue Ridge Lumber.

### LODGEPOLE PINE GENETICS AND RELATED RESEARCH

In order to develop necessary scientific information to aid genetic improvement of lodgepole pine and mass production of improved seed in seed orchards, the Alberta Forest Service has started several research studies (Dhir et al. 1980; Schilf et al. 1982). The purpose of this work is to develop information on the Alberta lodgepole pine population with regard to genetic variability, inheritance, and genetic relationships of traits of importance in applied breeding. Several studies on early induction of flowering and enhancing cone and seed production using physiological and cultural treatments are also in progress.

#### LITERATURE CITED

- Dhir, N.K.; vanBorrendam, W.; Schilf, J.; Flinn, P. Genetics and tree improvement research, Alberta Forest Service, 1977-1979. In: Proc. 17th Meet. Can. Tree Improv. Assoc., Part 2; 1980: 187-190.  
McDougall, F.W. The importance of lodgepole pine in Canada. In: Management of Lodgepole Pine Ecosystems: Symposium proceedings, Vol. 1; Pullman, WA: Washington State University, Coop. Ext. Svc.; 1975: 10-26.  
Schilf, J.M.; Dhir, N.K.; Flinn, P. Genetics and tree improvement research, Alberta Forest Service, 1979-1981. In: Proc. 18th Meet. Can. Tree Improv. Assoc., Part 2; 1982: 93-97.

## SEED PRODUCTION IN SEROTINOUS CONES OF LODGEPOLE PINE

A.K. Hellum

### INTRODUCTION

Lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) is a steady (Crossley 1956) and heavy cone producer (Clements 1910, Bates 1930). Mature trees commonly bear hundreds of cones at a time. Reforestation after fire (Tower 1909) and site preparation (Crossley 1976, Lotan 1975) often leads to establishment of dense stands (Johnstone 1981, Smithers 1961).

It was the purpose of this study to demonstrate that not only is lodgepole pine a light cone producer, but that cone morphology precludes efficient seed production even in the few cones which are formed.

The only reason that lodgepole pine regenerates itself so densely after disturbances is its particular reproductive strategy which gives the species a momentary advantage of heavy cone and seed retention. Or is it a disadvantage?

### METHODS

Data were assembled from a number of sources to establish the general relationship between tree age and size of cone crop in lodgepole pine (Clements 1910; Crossley 1956; Hellum and Barker 1981; Lotan 1967, 1968).

Because cones are retained on the tree for a number of years before they drop off, data were also analyzed to determine the rate of cone loss over time from standing trees (Crossley 1956, Hellum and Barker 1981, and unpublished data). Cone production was expressed as an annual percentage of the total cone crop on five trees on each of four sites in Alberta, two at 51°N (Crossley 1956) and two at 53°45'N (Hellum and Barker 1981).

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The serotinous cone crop data and the cone loss data were then combined to calculate the total rate of cone production for a stand over 100 years of cone production, or until age 117 years.

Nonserotinous cones were excluded from these considerations because their seeds are shed as they mature and do not, as a rule, contribute much to stand stocking and bear no relation to stand origin after fire or logging.

The two stands at 53°45'N, near Hinton, (Hellum and Barker 1981) were analyzed further to evaluate:

- total seed production by cone
- total seed production by tree and stand and
- seed retention in the cone even after vigorous attempts at seed extraction.

Five cones from each of the cones aged 3, 7, 11, 15, 19, 23, and 27 years (or as many of these ages of which there were representative cones present on individual trees) were "cracked open" at 180°C for 2 min. and then set into gravity-vented kilns at 60°C for 24 hours. They were subsequently tapped, tips down, against a table top fifteen times to release "all" seed. The cones were then picked apart by hand to yield the retained seed. A total of 238 cones were used for this test of total seed production and seed retention, representing five trees from each of two stands 110 years old.

An additional 70 cones from three trees (nos. 5, 9, and 10) were picked apart to determine where the seed was held in the cone.

Photos were taken of a number of cones, split lengthwise, both in a wet and dry condition, to show different bending moments and scale types in different parts of the cone.

### RESULTS

#### Cone production

About five cones per tree accrue each year for 100 years. This relationship ( $r^2=0.67$ ) could undoubtedly be improved upon

Table 1--Total crop of closed cones on five trees in each of four stands of lodgepole pine in Alberta based on data from Crossley (1956), Hellum and Barker (1981) and unpublished data.

Stand Notations	Tree	Total closed cones/tree	Percent of total crop
Stand at 51°N, open-grown trees, 61 years old on average (Crossley 1956)	1	12	2
	2	27	3
	3	1,102	55
	4	534	99
	5	183	98
	Average	372	51.4
51°N, closed canopy stand 69 years old on average (Crossley 1956)	6	221	76
	7	47	38
	8	116	25
	9	80	20
	10	376	94
	Average	168	50.6
53°45'N closed stand, flat, 110 years old (Hellum and Barker 1981, in part)	1	721	94
	2	678	94
	3	241	100
	4	331	100
	5	598	100
	Average	514	97.6
53°45'N closed stand, N-facing, 100 years old, (Hellum and Barker 1981)	6	540	75
	7	360	96
	8	352	70
	9	291	89
	10	160	90
	Average	341	84.0

by segregating stand data by stem density (table 1) and geographic origin (fig. 1), as well as by using many more observations than those available for this statement.

The species produces closed cones every year without showing marked signs of heavy or light cone years. Individual trees can produce over 200 cones in a given year, but quantities less than 30 cones/year/tree are much more common even at full tree maturity.

The average cone stays on the tree for about 15 years and hardly any cones remain on a tree for more than 30 years. (figs. 2 and 3). Neither site productivity nor stand age, site aspect, or stand density seem to alter this linear trend of cone loss. Squirrel feeding does not alter this trend either, because the feeding is confined exclusively to new cones.

This means that about 3% of the cones on a tree fall off each year. Combining the data from figure 1 and figures 2 and 3, assuming a net annual cone accretion of 5 cones and a net annual loss of 3%, figure 4 indicates that a tree 117 years old

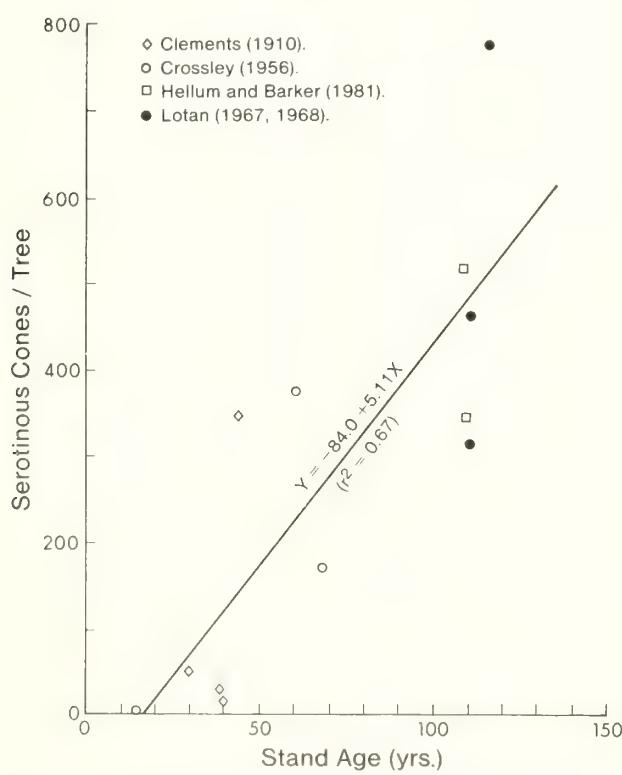


Figure 1. --Correlation between stand age and the number of serotinous cones retained by an average lodgepole pine tree.

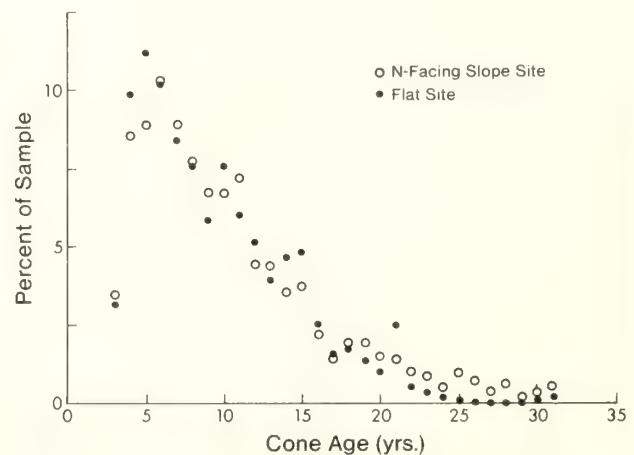


Figure 2. --Correlation between cone age on the tree and the number of retained cones, expressed as a percentage of all retained serotinous cones. Data represent two stands of lodgepole pine at 53°45'N, near Hinton, Alberta.

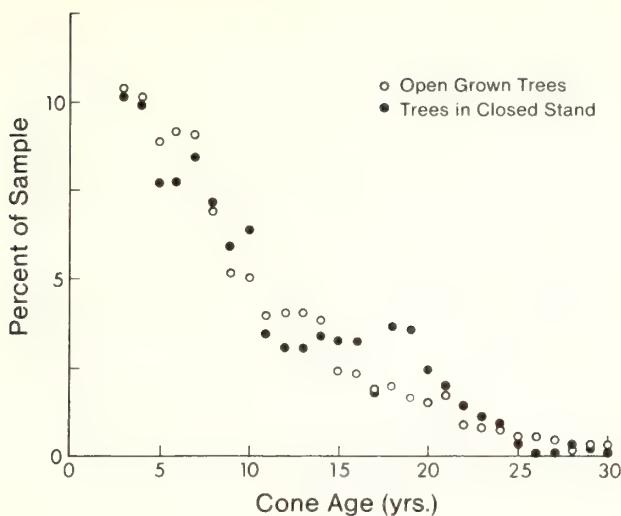


Figure 3. --Correlation between cone age on the tree and the number of retained cones, expressed as a percentage of all retained serotinous cones. Data represent two stands of lodgepole pine at 51°N, in the Kananaskis Valley, Alberta.

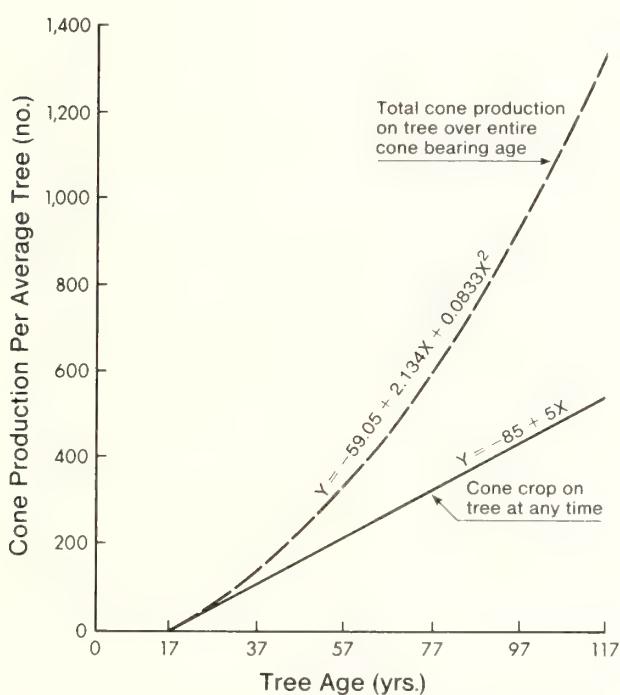


Figure 4. --Correlations between tree age and total retained serotinous cones and total cone production (serotinous) over the entire cone-bearing age of the tree.

Table 2 --Average seed yield per cone based on five cones each 3, 7, 11, 15, 19 and 23 years old (where available) per tree , for lodgepole pine from 53°45'N near Hinton, Alberta, and average percent empty seed.

Tree No.	Total seed per cone ( $\pm 1$ SD)	Sample size (cones)	% empty seed ( $\pm 1$ SD)	Tree No.	Total seed per cone ( $\pm 1$ SD)	Sample size (cones)	% empty seed ( $\pm 1$ SD)
1	20.3 ± 4.2	18	19.6 ± 19.6	6	36.0 ± 12.6	30	28.3 ± 18.7
2	31.1 ± 15.3	25	21.8 ± 12.6	7	31.4 ± 9.3	20	19.5 ± 9.8
3	28.0 ± 15.9	20	25.9 ± 18.6	8	30.1 ± 6.2	35	38.3 ± 38.6
4	35.4 ± 11.2	20	10.0 ± 7.6	9	29.8 ± 11.9	25	43.7 ± 13.6
5	27.8 ± 11.3	25	14.4 ± 13.9	10	42.2 ± 12.2	20	22.8 ± 6.9

Grand average full seed/cone: 23.6  
Grand average total seed/cone: 31.2

could, on average, be expected to have produced 1,333 serotinous cones over 100 years, of which 500 still remain on the tree.

Nearly 38% of all the closed cones ever produced by the average tree over 100 still remain on the tree at harvest time or at 117 years.

Both the stands at 51°N (60-70 years old) and at 53°45'N (110 years old) produced 10-11% additional cones each year, but the effect on cone accumulation on the tree was reduced to a linear rate of five cones/year because, as more cones were retained year by year, more also fell off.

#### Seed release

It was reported earlier (Hellum 1978) that an average bushel (36.37 l) of lodgepole pine cones might contain 1,487 cones judging by ten bulk samples from the major part of the species range in Alberta.

An average bushel yields 23,500 sound seeds (Krugman and Jenkinson 1974) or 15.8 sound seeds per cone using 1,487 cones per bushel. Yields between 13 and 29 seeds/cone (average 21) have been reported for Alberta based on careful seed extraction techniques (Wang 1978), but 15.1 (Lotan 1967) seeds is probably a good operational average for Alberta as well as Montana.

The 10 trees near Hinton produced from 16 to 33 full seeds/cone and tree (average 24) after cleaning (table 2).

These data suggest that about 35% of the full seed produced by an average cone of lodgepole pine may be retained and may not contribute to stand stocking after disturbances unless the retained seeds germinate within the cone and somehow are able to give rise to successful germinants.

#### Seed location in the cone

The average lodgepole pine cone appears to have three basic scale types judging by trees 5, 9, and 10 from near Hinton:

1. A basal scale which regularly has (a) a thick apophysis and sharp umbo, (b) comprises between 64 and 72% of the total weight of all cone scales, and (c) numbers between 70 and 115 scales per cone, depending on the tree.
2. A middle scale type which is wide and flat makes up from 20 to 27% of the scale weights and numbers between 17 and 25 scales per cone, depending on the tree.
3. An apical set of scales, bent lengthwise, one scale overlapping the next in closed cones, makes up from 8 to 9% of the scale weights and numbers between 10 and 12 scales per cone.

Category 1 scales appear to be sterile. They are attached to the cone axis by a narrow stem or a somewhat wider base. They are attached to the cone axis from the base of the cone to the point at which the pith section of the axis is at its widest. These



Figure 5.--These photographs show cross sections of lodgepole pine cones before (left) and after (right) opening. Cones of lodgepole pine have three distinct scale types which flex differently as cones open: a basal scale which bends in an elbow, a middle scale which bends along its entire length, and an apical scale which bends only at its base.

scales flex, during cone opening, by bending in an elbow joint some distance from the cone axis. The scales are too thick to bend anywhere else (fig. 5). These scales also contain more acetone-extractable materials than the other scale types (Hel-lum and Loken 1982), thus making them slower to take up water and to flex than more apical scales.

Category 2 scales appear to produce between 75 and 85% of the seeds in the cone with an average of 1.3 to 1.5 seeds per scale, according to the three sample trees and cone ages. These scales flex along their entire length.

Category 3 scales appear to produce the remaining 15 to 25% of the seed with an average of 0.6 to 0.8 seeds per scale, depending on the tree and cone age. These scales flex backwards only from their bases during cone opening. They are folded lengthwise and can not bend anywhere else.

By the above analysis of scales, trees 5, 9, and 10 produced between 59 and 70% of the seeds that could have been produced for the cone ages 3, 7, 11, 15, 19, and 23 (table 2).

#### Seed production per hectare

The average tree 100 years old on the flat site near Hinton bore 11,601 full seeds in serotinous cones, the sloping site had trees with an average of 7,938 seeds (table 3). At a maximum seed-

Table 3--Total full seed by tree and stand near Hinton, Alberta.

	Tree No.	Total closed cones	Total sound seed/tree
Flat Site	1	721	11,752
	2	678	16,475
	3	241	4,989
	4	331	10,559
	5	598	14,232
Average		11,601	
Sloped Site	6	540	13,932
	7	360	9,108
	8	352	6,547
	9	291	4,889
	10	160	5,216
Average			7,938

seed-retention rate of 35% in the cone, this still amounts to between 12 and 18 times more seed per fully stocked stand than that needed in Alberta to establish a stand with about 800 stems/ha after logging and site preparation.

#### DISCUSSION AND CONCLUSIONS

Lodgepole pine trees between 60 and 110 years old produced about 10-11% more cones each year than they retained from past years' production. At the same time, cones drop off at the approximate rate of 3% per year for every year, so virtually no cone remains more than 30 years. Cones fall off the tree because branches die and fall off, cone meristems die, and/or branches grow faster in diameter than cone meristems — thus forcing the cones to drop off.

The net effect of this accretion and loss is that an average tree bears only 5 more cones each year than the year before or about 500 cones after 100 years (serotinous cones only). This is nearly 40% of all the cones ever produced by an average tree.

Even if 500 cones/tree can shed between 12 and 18 times more seed than that needed for optimum stand development after fire or logging (one third of the seed is retained in the cones and cannot easily be extracted), it took the tree 100 years of cone production to accumulate this amount. This surely is not to be considered "heavy cone production."

In addition to such modest annual cone production, this study has shown that the cone of lodgepole pine produces few seeds, or only about one full seed per 4-5 scales because three quarters of the average cone is sterile.

The tendency of serotinous cones to produce excessive amounts of stored seed at tree maturity, their tendency to produce overstocked stands after disturbances, and the low seed production per cone seem to work in opposite directions regarding optimal species adaptation to site.

Has the species been a much more prolific seed producer in the past as the large sterile part of the cone suggests? Is high seed retention in the cone, even after cone opening, also a sign of cone inefficiency? Both factors certainly help to reduce the potential danger of stand stagnation from overcrowding after disturbance. But, trees can produce enough seed every 4-5 years

to regenerate themselves once they reach the age of 22 years or more, and this can therefore lead to serious stand stagnation problems later in the life of the stand because 30-year-old cones contain as many viable seed as new ones (Wang 1978).

Lodgepole pine may also have adapted its seed and cone production to accidental fires occurring soon enough to prevent overstocking and stagnation. At an average stand age of 67 years (Day 1972), or 77 years today in Alberta's southern foothills of Rocky Mountains, the average tree has six to nine times more seed (or 8.5 to 11.5 times more in a 77-year-old stand) than that needed for regeneration. This could mean that cone serotiny is poorly matched to current fire history (Givnish 1982, Perry and Lotan 1979) especially in Alberta.

#### LITERATURE CITED

- Bates, C. G. The production, extraction, and germination of lodgepole pine seed. U.S.D.A. Tech. Bulletin No. 191; 1930. 92 p.
- Clements, F. E. The life history of lodgepole burn forests. U.S.D.A. For. Ser. Bull. No. 79; 1910. 56 p.
- Crossley, D. I. Fruiting habits of lodgepole pine. Canada Dept. of Northern Affairs and National Resources. For. Br., Tech. Note No. 35; 1956. 32 p.
- . The ingress of regeneration following harvest and scarification of lodgepole pine stands. For. Chron. 52(1): 17-21; 1976.
- Day, R. J. Stand structure succession, and use of southern Alberta's Rocky Mountain Forest. Ecology 53(3):472-478; 1972.
- Givnish, T. J. Serotiny, geography and fire in the Pine Barrens of New Jersey. Evolution 35(1): 101-123; 1981.
- Hellum, A. K. Cone opening in lodgepole pine. Final report to Alberta Forest Dev. Research Trust, Alberta Energy and Natural Resources; 1978. 22 p. mimeo.
- . Lodgepole pine seed extraction using water and heat. Final Report, Alberta Forest Dev. Res. Trust, Alberta Energy and Natural Resources; 1980. 24 p. mimeo.
- Hellum, A. K.; Barker, N. A. The relationship of lodgepole pine cone age and seed extractability. Forest Science 27(1):62-70; 1981.
- Hellum, A. K.; Loken, A. (in press) Fro og konglemodning i *Pinus contorta* fra Alberta, Canada, 1980. (in press with Norsk Institutt for Skogforskning); 1982.
- Johnstone, W. D. Effect of spacing 7-year-old lodgepole pine in west-central Alberta. Northern Forest Research Centre Canadian Forestry Service, Environment Canada, Information Report NOR-X-236; 1981. 18 p.
- Krugman, S. L.; Jenkinson, J. L. *Pinus* L. Pine. In: Seeds of Woody Plants in the United States. U.S.D.A. Agriculture Handbook No. 450; 1974: 598-638.
- Lotan, J. E. Cone serotiny of lodgepole pine near West Yellowstone, Montana. For. Sci. 13(1):55-59; 1967.
- . Cone serotiny of lodgepole pine near Island Park, Idaho. U.S.D.A. For. Serv. Intermtn. For. and Rge. Expt. Sta. Res. Pap. INT - 52; 1968. 6 p.
- . Regeneration of lodgepole pine forests in the Northern Rocky Mountains. In: Proc. Management of Lodgepole Pine Ecosystems. Vol. II. Wash. State Univ. Coop. Ext. Service; 1975: 516-535.
- Perry, D. A.; Lotan, J. E. A model of fire selection for serotiny in lodgepole pine. Evolution 33(3): 958-968; 1979.
- Smithers, L. A. Lodgepole pine in Alberta. Dept. of Forestry Bull. No. 127; 1961. 153 p.
- Tower, G. E. A study of the reproductive characteristics of lodgepole pine. Proc. Soc. Am. For. 4(1): 84-106; 1909.
- Wang, B. S. P. Seed yield and germination requirements of Alberta white spruce and lodgepole pine. Alberta Forest Dev. Research Trust, Alberta Energy and Natural Resources Report No. 92; 1978. 26 p.

## SITE PREPARATION FOR NATURAL AND ARTIFICIAL REGENERATION OF LODGEPOLE PINE IN ALBERTA

S.I. Ferdinand

### INTRODUCTION

Lodgepole pine is one of the most valuable commercial trees in Alberta. It is the dominant forest tree along the foothills and the east slopes of the Rocky Mountains. Its range extends from the Canada-U.S. border in the south to 56° latitude north. Small, remote populations can be found further north but these are of limited economic value. By area, lodgepole pine types occupy approximately 3.37 million hectares, which represent 40.0 per cent of the coniferous forests and 22.3 per cent of the total productive forest land.

Approximately 70 per cent of the allowable annual cut in lodgepole pine has been committed to the wood-processing industries to date. The area harvested annually varies between 7,000 and 10,000 hectares. Harvesting is carried out in clear-cut patches, ranging between 16 and 80 ha in size.

In Alberta, all forest land is owned by the province. However, wood-harvesting rights are granted to members of the wood-processing industry through long-term (20-year, renewable) Forest Management Agreements, long-term Timber Quotas, and through short-term (max. 1 year) timber permits. Regardless of the type of tenure, the forest industry is directly responsible for the cost of reforestation. However, quota holders can elect to transfer the actual reforestation work to the Alberta Forest Service through payment of a reforestation levy. Thus both the Alberta Forest Service and members of the forest industry are actively engaged in reforestation of logged areas.

The reader should note that this report is intended to be a statement on operational practices presently employed in regenerating lodgepole pine. Most of the presentation is based on the personal observation and experience of the writer and on statistical data compiled by the Alberta Forest Service.

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### REFORESTATION POLICY AND STANDARDS

Both the reforestation policy and standards are supported by legislation and are applied to permanent forest land. A summary of each is presented here in order to provide the reader with a frame of reference for scarification.

#### Reforestation Policy

- a. All cutover forest land must be satisfactorily regenerated within 10 years after harvest.
- b. Artificial reforestation treatment, where required, must be completed within 2 years following harvest.
- c. Reforestation success must be measured through a standardized regeneration stocking survey by the end of the 7th year following harvest.
- d. Unsatisfactorily stocked areas identified by the survey must be retreated in the 8th year and resurveyed 3 years after treatment.

#### Reforestation Standards

- a. All cutovers must be restocked with a minimum of 800 evenly distributed, established seedling trees per hectare of specified species, age, and quality.
- b. Acceptable species include all native conifers with some limitation on alpine/balsam fir and hardwood on the coniferous regeneration sites.
- c. Minimum age for established seedling trees: 2 years for pines, 3 years for all other species, and 3 years on site for all planted stock.
- d. Satisfactorily restocked cutover blocks cannot contain understocked areas larger than 4 hectares.

### REFORESTATION STRATEGY FOR LODGEPOLE PINE

The strategy adopted in Alberta for regenerating lodgepole pine includes, to the greatest degree possible, the utilization of the usually abundant seed supply in the cone-bearing logging slash

and tree tops through scarification. This strategy was adopted at the time the compulsory reforestation policy was introduced (1955-1966) and is still in widespread use today. Consequently, site-preparation techniques that allow the utilization of the natural seed source were developed and are favored in operational reforestation. Planting is used only on those areas where satisfactory stocking was not obtained following scarification, or where scarification was not done for some reason. This strategy has served us rather well in meeting the stated reforestation objectives. Only relatively recently are some of the shortcomings, such as limited control over density and distribution of regeneration, being recognized.

As forest management develops and is intensified, a new reforestation strategy will probably replace the existing one. In the next step, a much greater reliance on stand establishment by planting is envisaged. In this phase, preference will be given to techniques that will limit and discourage seedling establishment from the slash-borne seed source and will accommodate large-scale planting operations.

Although the benefits of stand establishment by planting can be recognized readily on the theoretical level, in practice the advantages may not be so clear-cut. In 1982, stand establishment by site preparation and planting cost between 2.4 to 3.0 times (240-300 per cent) than that by scarification and the natural seed source. The advantages in increased growth and yield and in the value of the end product will have to be significant in order to offset the differences in initial investment. In spite of the cost difference, a large increase in planting of lodgepole pine is expected to take place when genetically improved seed becomes available, in or about 1997. It is expected that, until that time, large-scale planting of pine will be more a topic of discussion than action. Presently, only 10-20 per cent of the pine cutovers are regenerated by planting. The bulk (80-90 per cent) are regenerated by scarification and natural seeding.

#### THE ROLE OF SITE PREPARATION IN REFORESTATION

The term *site preparation* is applied to activities that are conscientiously designed to modify forest site conditions in order to make them more favorable for seedling establishment and growth. On the operational level, site preparation in Alberta is synonymous with mechanical scarification. Controlled burning has not been used here for site preparation to any significant degree.

In common usage, scarification denotes the disturbance (modification) of the forest floor, sometimes during but generally after harvesting by mechanical means to various degrees and depth. It can mean intermittent or continuous disturbance of the duff layer alone, total removal of the duff and logging debris, mixing of the duff and humus with mineral soil thus combining the "A" and "B" soil horizons.

The purpose of scarification is the creation of a favorable environment for the establishment and continued growth of the germinating seed and planted seedling. If done with care and with a thorough understanding of the factors affecting growth, scarification can accomplish the stated objective by allowing warming of the generally cold soils; by improving the water, oxygen and nutrient levels in the soil; and by lessening competition from unwanted vegetation, thereby providing the aerial part of trees with more favorable light and temperature regimes. While this statement is correct in general terms, quite often not all of the growth factors can be optimized or even improved with scarification. On some sites, one factor may be improved at the expense of another. Consequently, the actual scarification should be and, in most cases, is preceded by a detailed site evaluation.

The pretreatment site evaluation is known by a number of different names such as: Post-Harvest Surveys (P.H.S.) or Management Opportunity Surveys (M.O.S.). The process and degree of sophistication may vary from one district to another or from one organization to another, but the primary objective of each unit is the identification of the biologically and economically most efficient reforestation method. All take into account the most important site parameters, the availability of reproductive material (seed), and the physical limitations of specific scarification equipment. The final result of the post-harvest survey is a site-specific treatment prescription.

#### SITE PREPARATION FOR NATURAL REGENERATION OF LODGEPOLE PINE

The opportunity to utilize the seed stored in logging slash was recognized at about the same time formal forest management was adopted in Alberta (1955-1966). Crossley (1956) and Ackerman (1962) established the basic relationship between scarification and natural seeding of pine. Operational foresters quickly adopted these principles and applied them to practical reforestation. After a short period of experimentation with equipment and techniques, the anchor-chain drag scarifier was adopted for general use.

The anchor-chain drag is a relatively simple piece of equipment. It is comprised of three to seven pieces of heavy, stud-link, anchor chain, each approximately 6.0-7.5 m long. Opposite the stud on each link, one D8/D9-class crawler-track pin (used) is welded. These pins are approximately 25-30 cm long and 50-57 mm in diameter and project out at 90° from the chains. The individual chains are then attached to a sturdy spreader bar at 0.75- to 1.0-m intervals thus forming a flexible, spiked, harrow-type unit. The largest drags in use by the Alberta Forest Service weigh approximately 6.5 tons and need D7- to D8-class crawlers for towing. The smaller drags (3 to 4 chains wide) are usually towed by D6-class crawlers. Drag scarification is the treatment of choice on all accessible, dry to moist, pine cutovers where an adequate seed source exists.

When properly used, drag scarifiers create a good variety of favorable microsites for seed germination by mixing the duff with mineral soil, by exposing mineral soil, and by removing some of the unwanted competing vegetation that may be present.

The quality objective for drag scarification is:

- a. 40 per cent mineral soil exposure (M.S.E.) as measured by the line transect method perpendicular to the direction of travel (of drag), or
- b. between 60 and 65 per cent M.S.E. as measured by the milacre-plot method. M.S.E. is satisfactory when 60 per cent of the milacre (0.001 acre) sample plots contain at least 1 ft<sup>2</sup> of exposed mineral soil (in metric measurement, this would correspond to approximately 0.23 m<sup>2</sup> M.S.E. in each 10-m<sup>2</sup> sample plot).

Seed availability from the logging slash is quantified during the post-harvest assessment prior to scarification. The requirements may vary some from one organization to another. The Alberta Forest Service considers the seed supply adequate to achieve 80 per cent stocking on most "dry" sites when a minimum of 25,000 evenly distributed, closed pine cones per hectare are present. On moist sites, more cones per unit area are desirable as the quality of scarification may be below 40 per cent, competing vegetation maybe more abundant, and lower soil-surface and air temperatures may result in reduction in seed release from the serotinous cones.

The anchor-chain scarifier usually does an adequate job on areas with shallow duff (up to 7.5 cm deep) and light to moderate slash loads (to 50 tons/ha). On areas with deeper duff and heavier slash loads, the prime mover must also be equipped with the special toothed blade or a brush rake-type blade to increase the effectiveness of the chain scarifier. Coverage is contiguous on most areas, meaning 100 per cent of a particular cutover block is scarified whenever possible.

Timing scarification to follow logging, as well as timing it seasonally, can significantly affect the regeneration success. Drag scarification should be completed within 1 year after completion of harvest, preferably during the first summer season after the needles in the logging slash turn brown.

In Alberta, pine cones north of 53° lat. appear to be less serotinous and open more readily than those to the south. Delay in scarification in the northern part may result in seed loss and regeneration failure. In the southern part of the province, scarification may be delayed to the second year following harvest without serious loss of seed or detrimental effects on regeneration.

Presently, between 80 and 90 per cent of the pine cutovers are drag scarified. Only those located on steep terrain (>30 per cent slopes) and inaccessible areas are not scarified.

Regeneration success from drag scarification has been very good to date. Between 80 and 90 per cent of the scarified areas meet the minimum (80 per cent) stocking standard 7 years after harvest. Since only one tree per sample plot is recorded during the stocking surveys, no information on the density of regeneration is collected. Because of the pattern and quality of site preparation and the pattern and quantity of cone distribution, seed cast, and variations in site, regeneration densities significantly exceed the minimum requirement of 800 per hectare (Crossley 1976, Johnstone 1976, Bella 1976) at the 80 per cent stocking level. Densities vary between 2,000 and 40,000 per hectare, with averages falling in the 8,000 to 15,000 range at 10 years of age.

The high densities obtained to date are the result of the technique itself and the "over-kill" approach taken toward drag scarification in the past. In order to be safe, quite often more mineral soil than necessary has been exposed, even on areas with an over-abundant seed supply. Further refinements in the technique are feasible and are being implemented through improvements in quantifying the volume and distribution of the available seed and through adjustments in M.S.E. (by removal or addition of chains as needed). More recently, the anchor-chain drags have been replaced by the "shark-fin" barrel scarifiers in some areas in order to reduce M.S.E. and stand densities.

A number of professional foresters in Alberta are apprehensive about the high regeneration densities, fearing reduced growth through excessive competition and outright stagnation as happens in some fire-origin stands. I do not share this concern at this time. While the possibility for overcrowding and stagnation does exist, the probability is believed to be low.

Dense regeneration originating from drag scarification is significantly different from fire-origin stands in at least two aspects. First, these stands start at much lower densities than most fire-origin stands, and, second, the range in the age of the trees is increased. Because of the relatively slow release of seed, ingress up to 11 years is reported by Crossley and Johnstone (1976) following scarification in west-central Alberta. Together with variation in microsites and the genetic variability in the population, these factors will enhance the expression of dominance by potential crop trees and will reduce the probability of

stagnation. Perhaps a moderate amount of competition pressure is more beneficial to the developing lodgepole pine stand than is presently recognized.

#### SITE PREPARATION FOR ARTIFICIAL SEEDING

When and where site conditions are favorable (shallow duff, light to medium slash volume), the drag scarifiers, with or without the brush rake-type blades, are used to scarify for broadcast seeding. The objective in this case is the creation of high M.S.E. and diversity of microsites in both the horizontal and vertical plane. Seeding rates are inversely related to M.S.E. and vary from 70,000 to approximately 250,000 seeds per hectare depending on site conditions and on the natural seed source. Artificial seeding quite often only supplements the natural seed source.

On deep duff sites with heavy slash loads, more-drastic site-preparation techniques are used. These include the various plows (Marttiini; Cazes & Heppner; Craig-Simpson), brush rakes, and dozer blades. The disturbance with these machines is quite extensive, with M.S.E. usually exceeding the 40 per cent standard.

In the past few years, the Alberta Forest Service has experimented with seeding of spot-scarified areas. One of the spot scarifiers (Bracke) imported from Sweden is able to seed on the scarified spots during scarification. The results on a 300-ha area treated in this manner are not encouraging. Two thousand spots per hectare, each seeded with an average of eight lodgepole pine seeds per spot (75 per cent or more germination capacity) resulted in only 30 per cent stocking. The reasons for failure could not be identified on this project. More work is needed in this area.

#### SITE PREPARATION FOR PLANTING OF LODGEPOLE PINE

The scarification techniques vary according to site conditions and the type of planting operation. Two types of planting are generally recognized. The first and largest is the fill-in planting, followed by establishment planting.

Fill-in planting is usually required on areas where only partial stocking results from scarification. The most suitable equipment in this instance are the spot scarifiers such as the Bracke and the Leno. With the proper prime movers such as rubber-tired skidders, these machines do minimal (15-20 per cent) damage to existing young regeneration, provided its height does not exceed 1.0 m. The scarification results in improvements not only in the microsite but in planting quality and productivity as well. Quite often, the cost of scarification is recovered through reduction in the planting costs.

The spot scarifiers may also be used in site preparation for establishment planting. Typically, the objective is to create between 1,250 and 1,600 plantable spots per hectare. Planting may be carried out with container-grown or conventional, bare-root seedlings. However, none of the spot scarifiers are satisfactory for scarifying areas of very heavy competition from tall grass and shrubs.

The most difficult sites, those with deep duff, heavy slash loads, or those taken over by dense grass and brush, usually require and receive a more intensive scarification than can be accomplished with spot scarifiers. The equipment used in such areas include brush rakes and the various plows mentioned previously. All of these require relatively large crawler-type (D6-D8 class) prime movers. Care must be exercised in their use in order to avoid soil erosion.



Anchor chain drag scarifier.



Toothed blade. A companion to the anchor chain drag.



Fifteen-year-old lodgepole pine regeneration. The result of drag scarification and natural seeding.

## SUMMARY

Scarification has played an important role in the regeneration of lodgepole pine in Alberta during the past 20-25 years. It has successfully supplanted the role of wildfires in regenerating pine. Many of the man-made stands are already believed to be superior to those originating from wildfires. Further refinements in scarification techniques are possible and will undoubtedly be made as scarification is expected to be part of lodgepole pine management for a long time to come.

## LITERATURE CITED

- Ackerman, R.F. Regeneration following strip clearcutting, scarification and slash disposal in a lodgepole pine stand. Can. Dept. For. Tech. Note No. 123; 1962. 16 p.  
Anonymous. Alberta Forest Regeneration Survey Manual. Alberta Dept. Energy and Natural Resources, Forest Serv.; 1979; 43 p.



Lodgepole pine plantation on scarified ground.

- Anonymous. Alberta Forest Service Post Harvest Survey Manual; 1981. 20 p.  
Anonymous. The timber management regulations - AR 60/73. Government of The Province of Alberta; 1973. 31 p.  
Anonymous. Timber harvest cut block design. Alberta Energy and Natural Resources; ENR Report No. 43; 1977. 38 p.  
Bella, I.E. Assessment of regeneration stocking standards used in Alberta. Inf. Rep. NOR-X-167. Can. For. Serv.; 1976. 38 p.  
Crossley, D.I. Mechanical scarification and strip clearcutting to induce lodgepole pine regeneration. Note No. 34. Can. Dept. North. Aff. and Nat. Res., For. Br., For. Res. Div. Tech.; 1956. 13 p.

- The ingress of regeneration following harvest and scarification of lodgepole pine stands. For. Chron. 52: 17-21; 1976.  
Johnstone, W.D. Ingress of lodgepole pine and white spruce regeneration following logging and scarification in west-central Alberta. Info. Rep. NOR-X-170. Can. For. Serv.; 1976. 12 p.

## INSECT AND DISEASE PESTS AND ALLIED PROBLEMS AFFECTING LODGEPOLE PINE IN ALBERTA

W.G.J. Ives

### INTRODUCTION

Records compiled by the Forest Insect and Disease Survey over a 25-year period (Anon. 1953-1977) indicate that lodgepole pine, *Pinus contorta* Dougl. var. *latifolia* Engelm., is relatively free of catastrophic insect and disease pests and allied problems along the east slopes of the Rocky Mountains in Alberta. There are a few serious pests, however, and a number of other organisms that cause appreciable localized damage. Some pests are of minor concern only.

Although I shall discuss insects, diseases, and allied problems separately, it should be realized that this is an artificial separation. One often finds individual trees affected by all three types of damage.

I shall not attempt to describe the life histories or taxonomic characteristics of the pests involved, as these are covered in the literature. Papers by Hopping (1962), Nordin (1962), and Davidson and Prentice (1967) are particularly relevant.

### INSECT PESTS

#### Bark Beetles

The mountain pine beetle, *Dendroctonus ponderosae* Hopk., is one of the most serious forest insects in western Canada at the present time (Cerezke 1981, Van Sickle 1982). Historically, this insect has not been considered a problem in Alberta. The only outbreak reported in this province between 1906 and 1965 consisted of an infestation covering 4000 ha in 1940 along the Bow and Spray rivers (Hopping and Mathers 1945, Powell 1966). Selective cutting and cold weather in January 1943 apparently were responsible for terminating the outbreak.

The above outbreak history, when related to research on the effects of climate on brood development and overwintering survival, led researchers to believe that there was little likeli-

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hood of the mountain pine beetle's becoming a problem along the east slope in Alberta, even though areas of moderate hazard extend as far north as Jasper on the British Columbia side of the continental divide (Safranyik et al. 1974, Safranyik 1978). In general terms, the hazard map presented by Safranyik et al. (1974) is probably still fairly meaningful, but there is currently an outbreak in southern Alberta in an area to which they had assigned a very low hazard rating.

The Alberta outbreak was first observed at scattered locations along the east slopes between the United States-Canada border and the Carbondale River in 1977, and probably started in 1976 (Wong and Petty 1978). By 1980 it had expanded and intensified: over 79 km<sup>2</sup> were infested and over one million trees had been killed (Hiratsuka et al. 1981). Extensive sanitation cuttings were undertaken by the Alberta Forest Service in late 1980 and in 1981 in an attempt to limit the spread of the outbreak. These efforts appear to have been partially successful. The outbreak has not been arrested, but the amount of spread and population increase are both less than might otherwise have occurred (Hiratsuka et al. 1982).

We still believe that lodgepole pine stands on the east slopes north of the Trans-Canada Highway should be safe from attack by the mountain pine beetle. A combination of cool summers and unfavorable winters is believed to be a sufficient climatic barrier to prevent the build-up of populations. In light of the experience in southern Alberta, however, it is impossible to state categorically that an outbreak will not occur. Sources of infection may develop to the west of the Continental Divide, and these could conceivably initiate outbreaks on the east slopes, provided that suitable climatic conditions (hot summers and favorable winters) occurred simultaneously in both areas.

Several other species of bark beetles attack lodgepole pine, but these are usually of minor importance in Alberta. The lodgepole pine beetle, *Dendroctonus murrayanae* Hopk., sometimes kills trees weakened by fire or the climatic damage known as "red belt." Many of these trees might recover without the beetle attacks. The pine engraver, *Ips pini* (Say), occasionally kills healthy lodgepole pine when beetle populations reach large numbers on slash or other suitable material (Bright 1976, Furniss and Carolin 1977). Usually, however, the insects seem

to attack only trees that have been weakened by drought or some other cause. Other *Ips* species breed on lodgepole pine slash, but rarely cause a problem with living trees.

#### Woodborers

A number of woodborers in four taxonomic groups (cerambycids, buprestids, scolytids, and siricids) attack standing lodgepole pine and other coniferous tree species after fires, thus shortening the period during which salvage operations may be conducted. In Alberta, a common woodborer is the white-spotted sawyer beetle, *Monochamus scutellatus* (Say). This species can become a problem during logging operations, especially if summer-cut logs are left in decks for prolonged periods following exposure to ovipositing female beetles. Logs cut during early winter are less vulnerable to attack (Raske 1973). The volume loss in logs destined for use as pulp is less than 5% (Prentice and Campbell 1959), but the bore damage is more detrimental in lumber production (Prebble and Gardiner 1958). The damage is particularly important in logs intended for use as power poles because rigid grading standards allow virtually no sawyer holes (Cerezke 1975).

#### Weevils

A number of weevils cause damage to lodgepole pine in Alberta. Infestations of Warren's collar weevil, *Hylobius warreni* Wood, are widespread at lower elevations in the foothills and in the Cypress Hills. The feeding damage girdles and kills smaller trees and may provide ports of entry for disease organisms on larger trees (Cerezke 1970a). The numbers of weevils were found to be directly related to tree size, stand age, and duff thickness, and inversely related to stand density (Cerezke 1970a, 1970b). The weevil is considered to be an important insect in thinned and planted young pine stands (Hiratsuka et al. 1981).

The lodgepole terminal weevil, *Pissodes terminalis* Hopping, kills the current year's terminal growth on young trees (Drouin et al. 1963), and the white pine weevil, *P. strobi* (Peck), kills the previous year's terminal growth. Attacks by either species may result in multiple leaders and crooked stems (Johnstone 1981), while repeated attacks may cause the formation of "cabbage-topped" trees of little or no value. Neither species seem to have caused much damage in Alberta, but observations in Ontario (Anon. 1961-1972) indicate that the white pine weevil may become a serious problem in widely spaced plantations. The lodgepole pine weevil also prefers open-grown young stands (Drouin et al. 1963, Furniss and Carolin 1977, Stevenson and Petty 1968), so there is a danger that it may become a more serious pest as thinning of young stands becomes more prevalent. The strawberry root weevil, *Otiorrhynchus ovatus* L., has caused heavy losses of coniferous seedlings in nursery beds, but this appears to have been an unusual occurrence (Anon. 1967).

#### Pitch Twig Moth

The northern pitch twig moth, *Petrova albicapitana* (Busck), and the metallic pitch nodule moth, *P. metallica* (Busck), both attack young lodgepole pine in Alberta (Miller 1978). *P. albicapitana* has a 2-year life cycle (Turnock 1953). Feeding by first-year larvae causes little damage, but second-year larvae sometimes kill the terminals. The feeding damage usually causes the formation of crooked and weakened stems. Turnock (1953) considered lodgepole pine to be particularly susceptible to attack by this insect, but little damage has been reported in Alberta (Anon. 1953-1977, Stark 1957). However, a several-fold increase has been observed in mechanically thinned stands

in recent years (Sterner and Davidson 1981). Larvae of *P. metallica* feed more on the cortical tissue than on pith and xylem (Miller 1978). Because both insects are pests of young trees, it is conceivable that they may become more important in the future when large areas of young pine become more common.

#### Defoliators

The lodgepole needle miner, *Eucordylea starki* (Free.), reached outbreak proportions in the 1940s over an area of about 1200 km<sup>2</sup>, primarily in Banff and Jasper national parks (Stark 1954). Little mortality is caused even by prolonged attack, but there is a danger that weakened trees may be vulnerable to attack by the mountain pine beetle (Stark 1954). However, the present mountain pine beetle outbreak has occurred in an area not infested by needle miners in recent years. *E. biopes* (Free.) reached moderate to high population levels in the Banff area in 1981 (Hiratsuka et al. 1982).

The jack pine budworm, *Choristoneura pinus pinus* (Free.), and the sugar pine tortrix, *C. lambertiana* (Busck), cause top-killing of their hosts. The jack pine budworm is a major pest of jack pine in Manitoba, central Saskatchewan, northwestern Ontario, and the Lake states (Brandt and McDowall 1968, Cerezke 1978, De Boo and Hildahl 1968, Dixon and Benjamin 1963). The sugar pine tortrix has caused heavy defoliation of lodgepole pine in Idaho and Montana (McGregor 1970). Neither species has caused damage to lodgepole pine in Alberta.

*Neodiprion nanulus contortae* (Ross) has been reported in Alberta (Furniss and Carolin 1977), but has not caused any significant damage. Other defoliators attack lodgepole pine but are of minor importance.

#### DISEASE PESTS

With the exception of foliar diseases, tree diseases fluctuate less from year to year than forest insects. Any fluctuations are more likely to be spatial or of a long-term nature, often related to stand age and history. Consequently, the information on diseases collected by the Forest Insect and Disease Survey (Anon. 1953-1977) tends to reflect the intensity of effort as much as the importance of a particular disease. In total, however, these records provide a reasonably accurate picture of the importance of the various disease organisms, especially when supplemented by information contained in a number of research papers.

#### Dwarf Mistletoe

Dwarf mistletoe, *Arceuthobium americanum* Nutt. ex Engelm., is a parasitic plant that principally attacks lodgepole and jack pine in Alberta, causing an estimated annual loss of more than 270,000 m<sup>3</sup> (Baranyay 1970). It is considered to be one of the most destructive diseases of lodgepole pine in Alberta, and affects trees of all ages (Nordin 1962). Studies of factors influencing the damage caused by dwarf mistletoe (Baranyay and Safranyik 1970) show that there are no simple relationships, although volume losses in lodgepole pine are affected by site, duration of infection, and age of stand when first infected. Trees infected when young will not reach merchantable size. Heavily infected trees suffer considerable volume loss, particularly in the upper portions of the crown on dry sites, because height growth is reduced. "Witches' brooms" may be small or nonexistent in dense stands, but are quite noticeable on open-grown or thinned stands (Nordin 1962). Attempts to control the disease by repeated sanitation cutting and pruning were unsuccessful (Van Sickle and Weggitz 1978). Complete removal of infested trees before reforestation is probably the only

practical solution, and the cut-over areas should be relatively large to minimize the amount of reinfection from the residual stand. Baranyay (1970) indicated that mistletoe infection from one parasitized residual in a stand of young trees could spread more than 45 m in 80 years.

#### Red Stain and Decay

Red stain is the early stage of decay associated with a number of different fungi (Nordin 1962). Forest Insect and Disease Survey records (Anon. 1953-1977) give little indication of its importance because specialized assessment is required. One study conducted in 85-year-old stands near Nordegg, Strachan, and Water Valley revealed that more than 80% of 183 trees were infected with red stain fungi (Nordin 1962). A much larger survey in the upper and lower foothills section of the boreal forest in Alberta indicated that 45% of 2436 trees had red stain, while 7% had measurable advanced decay (Robinson-Jeffrey and Loman 1963). Decay was found to be unimportant in stands less than 100 years old (Loman and Paul 1963). In older stands, most of the decay occurred in a few trees and *Fomes pini* (Thore) Lloyd was the most important trunk-decaying organism. *Peniophora pseudo-pini* (Weres. and Gibson) was associated only with red stain, while *Conio-phora puteana* (Schum ex Fr.) Karst. was isolated from brown cubical root and butt rot. Other organisms were associated with root and butt rots.

A widespread root rot, *Armillaria mellea* (Vahl ex Fr.) Quél., sometimes causes mortality in young lodgepole pine stands (Anon. 1954, Baranyay and Stevenson 1964, Nordin 1962). Older stands are also affected, however, and 31% of the trees in a 73-year-old stand of lodgepole pine near Hinton were killed by the disease (Anon. 1964).

#### Atropellis Canker

The cankers caused by the fungus *Atropellis piniphila* (Weir) Loman and Cash are widespread on lodgepole pine in the foothills area of Alberta, and some stands are heavily infected (Anon. 1960, 1971). Surveys conducted in the Coalspur-Robb area in 1954 and 1955 (Anon. 1955, 1956) showed that over 70% of the pine were infected in an area covering about 325 km<sup>2</sup>. Forty to 70% of the trees in an area of 470 km<sup>2</sup> surrounding the heaviest infection were also infected. Smaller areas of moderately to heavily infected lodgepole pine were noted elsewhere on the east slopes (Anon. 1957). The cankers do not seem to kill the trees very quickly, but they and their associated blue-black stain degrade both pulpwood and lumber.

#### Stem Rusts

Several species of stem rusts attack lodgepole pine in Alberta. Most have life cycles involving alternate hosts, but one species can spread from pine to pine (Ziller 1974). Western gall rust, *Endocronartium harknessii* (J.P. Moore) Y. Hirat., has no known alternate host in Alberta, and is "the most common, most conspicuous, and most destructive stem rust of hard pines in western Canada" (Ziller 1974). It is recognized as being "one of the most important disease problems of man-made and man-assisted, young, hard-pine forests" (Hiratsuka et al. 1981). Damage is compounded by rodents and insects (Wong 1972), which frequently feed on the galls. The disease is widely distributed in Alberta (Anon. 1960).

Stalactiform blister rust, *Cronartium coleosporioides* (Arth.), is also widely distributed in Alberta, and moderate to severe infections on lodgepole pine have been reported at a number

of locations (Anon. 1953-1977). These infections have occasionally caused severe mortality among lodgepole pine saplings. *Commandra* blister rust, *Cronartium commandrae* (Peck), and sweetfern blister rust, *C. comptoniae* (Arth.), are both common in Alberta. *C. commandrae* occasionally causes serious injury (Anon. 1960, 1965).

#### Foliar Diseases

A number of organisms cause needle diseases on lodgepole pine (Hepting 1971). Several needle cast fungi, particularly *Lophodermella concolor* (Dearn.) Darker and *L. montivaga* (Petr.), have occasionally caused moderate or severe damage to lodgepole pine foliage at a number of locations in Alberta (Anon. 1953-1977). The diseases cause foliage discoloration and premature needle drop, but do not affect tree growth unless the infection is unusually severe. Another needle cast disease, *Elytroderma deformans* (Weir) Darker, is known to infect trees systemically and infections survive within the trees, eventually deforming them. The importance of this disease may be underestimated at the present time.

Needle rusts on lodgepole pine are caused by a number of organisms (Hepting 1971), but the western pine-aster rust, *Coleosporium asterum* (Diet.) Syd., is the only species reported to cause infections in Alberta (Anon. 1953-1977). It causes only moderate or minor damage (Ziller 1974).

#### ALLIED PROBLEMS

In addition to insect and disease pests, lodgepole pine trees are adversely affected by a variety of biotic and abiotic environmental factors. I shall not attempt to discuss all of these, because little information on their overall importance is available, but climatic and mammal damage occur so frequently that a brief discussion is warranted.

#### Climatic Damage

Drought, flooding, spring frosts, and hail all affect lodgepole pine adversely: damage is usually sporadic, although it may occasionally be extensive. Winter injury of lodgepole pine, commonly known as "red belt", is much more common (Anon. 1953-1977). The exact cause is unknown, but it is generally believed to be due to sudden temperature change in late winter or early spring (Robins and Susut 1974). The damage sometimes occurs in belts along hillsides, hence the name "red belt," but it may also occur in irregular patches. Injured trees usually recover, though they may lose much of their foliage. There may occasionally be extensive mortality, if the climatic damage is severe. Thousands of hectares of lodgepole pine in the upper foothills were destroyed in this manner in 1971, and more than 5000 ha were killed in the Cadomin area alone (Robins and Susut 1974).

#### Mammal Damage

Several groups of animals damage forest trees (Johnstone 1981). The snowshoe or varying hare, *Lepus americanus* (Erxleben), has peaks in populations approximately every 10 years. Extensive damage to stands of young lodgepole pine have often been observed in areas where there is adequate cover for the hares. Normally, small saplings have been considered to be most vulnerable, because the hares clip off saplings up to 2 cm and girdle those larger than this. It was believed that the trees should be relatively immune to further attack if they escaped damage in one hare population cycle (Sullivan 1980). This is

not always true, however. Some trees more than 10 cm in diameter at the base have been partially or completely girdled, usually just above the ground level. There is some disagreement among various "experts" as to what animal is causing the damage: some claim that it is attributable to porcupines, while others suggest that it is caused by squirrels. I do not profess to be an expert, but I have seen enough circumstantial evidence to convince me that the damage has been done by snowshoe hares. Some people have actually seen them chewing at the trees, but were unable to photograph the event. The extent of damage during the current peak in hare populations has not been adequately assessed, but it seems to be extensive.

Other mammals also cause damage by girdling or browsing on trees or saplings, but are of relatively minor importance. Porcupines, *Erethizon dorsatum* (L.), sometimes damage groups of trees, and meadow voles, *Microtus pennsylvanicus* (Ord), occasionally cause serious damage to trees in young stands, especially if there is extensive cover (Cayford and Haig 1961). Red squirrels, *Tamiasciurus hudsonicus* (Erxleben), frequently feed on rust galls and, in so doing, they sometimes girdle the stems or branches. They sometimes clip leaders or branches as well. Large game animals occasionally browse the tops of trees in young stands.

## DISCUSSION

Lodgepole pine grows faster at a relatively wide spacing, and dense stands respond well to thinning, provided it is done when the trees are relatively young. The amount of thinning has therefore been increasing in recent years, as the management of pine stands intensifies. There is no doubt that this practice increases the growth rate if the trees have been too crowded, but unfortunately it is not without a certain amount of risk. Any significant amount of tree mortality between thinning and harvesting may nullify the increased yield that the thinning was intended to achieve, and this mortality can occasionally be appreciable.

Throughout this paper I have noted that there is accumulating evidence that certain organisms seem to be a greater problem in open-grown stands. At the moment, much of the evidence is circumstantial. Future strategy concerning management of young lodgepole pine stands may need to be modified, however, should the trends be corroborated by further observation. Spacing may require modification to achieve some form of compromise that will avoid undue suppression of tree growth without favoring the build-up of pest populations. Adoption of this approach should help to reduce the need for costly pest-suppression measures without seriously affecting ultimate yields.

## LITERATURE CITED

- Anonymous. Annual reports of the Forest Insect and Disease Survey, 1952-1976. Ottawa, Ont.: Environ. Can., Can. For. Serv.; 1953-77.
- Baranyay, J.A. Lodgepole pine dwarf mistletoe in Alberta. Publ. 1286. Ottawa, Ont.: Dep. Fish. For., Can. For. Serv., 1970.
- Baranyay, J.A.; L. Safranyik. Effect of dwarf mistletoe on growth and mortality of lodgepole pine in Alberta. Publ. 1285. Ottawa, Ont.: Dep. Fish. For., Can. For. Serv.; 1970.
- Baranyay, J.A.; G.R. Stevenson. Mortality caused by *Amilalaria* root rot, peridermium rusts and other destructive agents in lodgepole pine regeneration. For. Chron. 40:350-361; 1964.
- Brandt, N.R.; L.L. McDowell. Jackpine budworm in Manitoba and Saskatchewan 1938-1967. Rep. MS-X-8. Winnipeg, Manit.: Can. Dep. For. Rural Devel., For. Br., For. Res. Lab.; 1968.
- Bright, D.E., Jr. The bark beetles of Canada and Alaska (Coleoptera: Scolytidae). Publ. 1576. Ottawa, Ont.: Can. Dep. Agric., 1976.
- Cayford, J.H.; R.A. Haig. Mouse damage to forest plantations in southeastern Manitoba. J. For. 59:124-125; 1961.
- Cerezke, H.F. Biology and control of Warren's collar weevil, *Hylobius warreni* Wood, in Alberta. Intern. Rep. A-27. Calgary, Alberta: Dep. Fish. For., Can. For. Serv., For. Res. Lab.; 1970a.
- . Survey report of the weevil, *Hylobius warreni* Wood, in the foothills of Alberta. Intern. Rep. A-38. Edmonton, Alberta: Dep. Fish. For., Can. For. Serv., For. Res. Lab.; 1970b.
- . White-spotted sawyer beetle in logs. Inf. Rep. NOR-X-129. Edmonton, Alberta: Environ. Can., Can. For. Serv., North. For. Res. Cent.; 1975.
- . Jack-pine budworm (*Choristoneura pinus pinus* Free.) in the Nisbet Provincial Forest of Saskatchewan: An analysis of the current situation. File Rep. NOR-143. Edmonton, Alberta: Fish. Environ. Can., Can. For. Serv.; 1978.
- . An overview of the problem. In: Mountain pine beetle symposium. 1981 Feb. 6-7; Coleman, Alberta. Edmonton, Alberta: Energy and Nat. Resources, For. Serv.; 1981: 4-8.
- Davidson, A.G.; R.M. Prentice. Important forest insects and diseases of mutual concern to Canada, the United States and Mexico. Publ. 1180. Ottawa, Ont.: Can. Dep. For. Rural Devel.; 1967.
- DeBoo, R.F.; V. Hildahl. Jackpine budworm in central Canada. Liaison Serv. Note MS-L-14. Winnipeg, Manit.: Can. Dep. For. Rural Dev., For. Branch, For. Res. Lab.; 1968.
- Dixon, J.C.; D. M. Benjamin. Natural control factors associated with the jack-pine budworm, *Choristoneura pinus* J. Econ. Entomol. 56:266-270; 1963.
- Drouin, J.A.; C.R. Sullivan; S.G. Smith. Occurrence of *Pissodes terminalis* Hopp. (Coleoptera: Curculionidae) in Canada: Life history, behaviour, and cytogenetic identification. Can. Entomol. 95:70-76; 1963.
- Furniss, R.L.; V.M. Carolin. Western forest insects. Misc. Publ. 1339. U.S. For. Serv.; 1977.
- Hepting, G.H. Diseases of forest and shade trees of the United States. Handb. 386. U.S. For. Serv. Agric.; 1971.
- Hiratsuka, Y.; H.F. Cerezke; B.H. Moody; J. Petty; G.N. Still. Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1981 and predictions for 1982. Inf. Rep. NOR-X-239. Edmonton, Alberta: Environ. Can., Can. For. Serv. North. For. Res. Cent.; 1982.
- Hiratsuka, Y.; H.F. Cerezke; J. Petty; G.N. Still. Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1980 and predictions for 1981. Inf. Rep. NOR-X-231. Edmonton, Alberta: Environ. Can., Can. For. Serv., North. For. Res. Cent.; 1981.
- Hopping, G.R. Insects injurious to lodgepole pine in the Canadian Rocky Mountain Region. In: Smithers, L.A., ed. Lodgepole pine in Alberta Bull. 127. Ottawa, Ont.: Can. Dep. For., 1962:77-87.
- Hopping, G.R.; W.G. Mathers. Observations on outbreaks and control of the mountain pine beetle in the lodgepole pine stands of western Canada. For. Chron. 21:98-108; 1945.
- Johnstone, W.D. Effects of spacing 7-year-old lodgepole pine in west-central Alberta. Inf. Rep. NOR-X-236. Edmonton, Alberta: Environ. Can., Can. For. Serv., North. For. Res. Cent.; 1981.
- Loman, A.A.; and G.D. Paul. Decay of lodgepole pine in two foothills sections of the boreal forest in Alberta. For. Chron. 39:422-435; 1963.
- McGregor, M.D. Biological observations on the life history and

- habits of *Choristoneura lambertiana* (Lepidoptera: Tortricidae) on lodgepole pine in southeastern Idaho and western Montana. Can. Entomol. 102:1201-1208; 1970.
- Miller, W.E. *Petrova* pitch-blister moths of North America and Europe: Two new species and synopsis (Olethreutidae). Ann. Entomol. Soc. Am. 71:329-340; 1978.
- Nordin, V.J. Forest diseases of lodgepole pine in Alberta. In: Smithers, L.A., ed. Lodgepole pine in Alberta. Bull. 127. Ottawa, Ont.: Can. Dep. For.; 1962: 87-97.
- Powell, J.A. Distribution and outbreaks of *Dendroctonus ponderosae* Hopk. in forests of western Canada. Inf. Rep. A-X-2. Calgary, Alberta: Dep. For., Can. For. Serv., For. Res. Lab.; 1966.
- Prebble, M.L.; L.M. Gardiner. Degrade and value loss in fire-killed pine in the Mississaga area of Ontario. For. Chron. 34:139-158; 1958.
- Prentice, R.M.; A.E. Campbell. Volume loss of pulpwood in Manitoba caused by woodborers. For. Chron. 35:142-145; 1959.
- Raske, A.G. Relationship between felling date and larval density of *Monochamus scutellatus*. Ottawa, Ont.: Environ. Can., Can. For. Serv. Bi-Mon. Res. Notes 29(4):23-24; 1973.
- Robins, J.K.; J.P. Susut. Red belt in Alberta. Inf. Rep. NOR-X-99. Edmonton, Alberta: Environ. Can., Can. For. Serv., North. For. Res. Cent.; 1974.
- Robinson-Jeffrey, R.C.; A.A. Loman. Fungi isolated in culture from red heartwood stain and advanced decay of lodgepole pine in Alberta. Can. J. Bot. 41:1371-1375; 1963.
- Safranyik, L. Effects of climate and weather on mountain pine beetle populations. In: Kibbee, D.L., ed. Theory and practice of Mountain pine beetle management in lodgepole pine forests. Moscow, ID: Univ. Idaho; 1978:77-84.
- Safranyik, L.; D.M. Shrimpton; H.S. Whitney. Management of lodgepole pine to reduce losses from the mountain pine beetle. For. Tech. Rep. 1. Victoria, B.C.: Environ. Can., Can. For. Serv., Pac. For. Res. Cent.; 1974.
- Stark, R.W. Distribution and life history of the lodgepole needle miner (*Recurvaria* sp.) (Lepidoptera: Gelechiidae) in Canadian Rocky Mountain National Parks. Can. Entomol. 86:1-12; 1954.
- \_\_\_\_\_. Pitch nodule maker in Banff National Park. Can. Dep. Agric., Sci. Serv. For. Biol. Div. Bi-Mon. Prog. Rep. 13(4):2-3; 1957.
- Sterner, T.E.; A.G. Davidson. Forest insect and disease conditions in Canada 1980. Ottawa, Ont.: Environ. Can., Can. For. Serv., For. Ins. Dis. Surv.; 1981.
- Stevenson, R.E.; J. Petty. Lodgepole terminal weevil (*Pisoides terminalis* Hopkins) in the Alberta/Northwest Territories region. Ottawa, Ont.: Can. Dept. For. Rural Dev. Bi-Mon. Res. Notes 24(1):6; 1968.
- Sullivan, T.P. Animal damage affected by spacing trees. B.C. Lumberman 64(12):34-35; 1980.
- Turnock, W.J. Some aspects of the life history and ecology of the pitch nodule maker, *Petrova albicapitana* (Busck) (Lepidoptera: Olethreutidae). Can. Entomol. 85:233-243; 1953.
- Van Sickie, G.A. The mountain pine beetle situation in Canada. In: Proc. Joint Canada/USA workshop on mountain pine beetle related problems in western North America. Inf. Rep. BC-X-230. Victoria, B.C.: Environ. Can., Can. For. Serv., Pac. For. Res. Cent.; 1982.
- Van Sickie, G.A.; E. Weggitz. Silvicultural control of dwarf mistletoe in young lodgepole pine stands in Alberta and British Columbia. Inf. Rep. BC-X-180. Victoria, B.C. Environ. Can., Can. For. Serv., Pac. For. Res. Cent.; 1978.
- Wong, H.R. *Dioryctria banksiella* (Lepidoptera: Pyralidae) in the western gall rust, *Endocronartium harknessii* (Basidiomycetes: Uredinales). Can. Entomol. 104:251-255; 1972.
- Wong, H.R.; J. Petty. The mountain pine beetle in Alberta. Ottawa, Ont.: Environ. Can., Can. For. Serv. Bi-Mon. Res. Notes 34(6):38; 1978.
- Ziller, W.G. The tree rusts of western Canada. Publ. 1329. Victoria, B.C.: Can. For. Ser.; 1974.

## LAND-USE CONFLICT IN WEST-CENTRAL ALBERTA, PARTICULARLY WITHIN THE ST. REGIS (ALBERTA) LTD. FOREST MANAGEMENT AREA

Raymond Ranger

### INTRODUCTION

St. Regis (Alberta) Ltd., with its manufacturing facilities and head office in Hinton, is the producer of high-quality bleached kraft pulp and, more recently, has entered the field of railroad-tie and kiln-dried stud production.

The government of the province of Alberta is the custodian of our provincial forest resources and, as such, was granted the first management agreement to the company in 1954. The history of the company's association with the government and the Department of Energy and Natural Resources, has been one of mutual cooperation in the development of a forest-management program suited to the province's particular needs. While details might differ from one government administration to another, the principles underlying a good forest-management program are virtually the same everywhere.

Our formal agreement with the crown includes three main clauses designed specifically to protect the public's interest in the resource that the company manages as well as provide for overall resource development within the province.

The main context of these clauses are as follows:

1. Our agreement is for intervals of 20 years, with automatic renewals depending upon adequate performance.
2. Multiple use of the land is mandatory but, in this context, it is recognized that the growing of timber is its *prime* use.
3. The company is obliged to "Follow sound Forestry practices with the objective of achieving and maintaining a perpetual sustained timber yield from the productive forest land." This means that our yearly harvest of timber shall not exceed that which can be replaced by the annual growth.

The forest-management area is not only an area of prime timber but is also rich in coal deposits and petroleum and natural gas resources. The exploration and development of these reserves

contributes greatly to the province's economy, and, while these activities are not without certain irritants to the successful management of the land for timber production, ways must be found to accommodate the nonrenewable-resource industries in their quest to develop these subsurface resources.

Thus, the stage is set for the frequent irritation, reluctant accommodation, or downright continuous conflict which can and does occur when activities involving the use of renewable and nonrenewable resources are allocated equal rights on the same acre of ground.

### CONFLICTS

The three more common conflicts that we experience, on a day-to-day basis, are:

- a) conflicts associated with coal exploration and development (strip mining),
- b) conflicts associated with the exploration and development of oil and natural gas, and
- c) conflicts associated with usage and/or disruption to our existing or planned infrastructure.

#### Coal Exploration and Development

The forest management area, which covers some 2 million acres of wild land on the east slope of the Rocky Mountains, is contained within fixed boundaries; and its harvesting and production operations are restricted by an allowable annual cut which is based on the capacity of its fixed land base to produce or grow timber of a certain species, size, and quality.

Underlying this land base are ribbons of rich coal seams which await development, it would seem, at the whim of foreign markets. Fully one third of our forest management area contains coal leases which are so located and which contain enough volume to be deemed viable future mining prospects. As such, they are held under lease to be stripmined or developed in the foreseeable future.

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If, in fact, the total or, for that matter, any appreciable amount of these proposed strip mines are developed with a short period of time (and I speak here of a period of, say, one rotation of 80 years), then it is easy to see that a program of sustained yield could not be maintained without a considerable addition of forested lands to augment our forest land base.

In addition to the loss of a considerable amount of land base, the strip mines have an additional adverse effect: their elongated form of development cuts timber operating areas virtually in two, thus dictating that two or more access and haul routes are required where formerly one would do. Further, above-ground overland conveyor belts planned to deliver the coal to major railroad marshalling points again pose considerable logging, roading, and other logistic problems.

#### Exploration and Development of Oil and Natural Gas

In addition to the rich reserves of coal underlying the forest floor, in the late fifties large amounts of oil were discovered, as well as an even larger quantity of natural gas which is distributed pretty much throughout the entire forest management area. These reserves have been discovered beneath the surface at both the 6-8,000- and 14,000-foot levels, and make up part of the overall reserves that class Alberta as the Oil Capital of Canada.

Subsequently, between the commencement of geophysical activity within the forest management area in the late 1950s and the end of 1981, some 6,600 miles of seismic exploration lines have been established by the petroleum industry, involving over 20,000 acres of timberland. The straight-line nature of these exploration lines ignores land contours, thus making it difficult to salvage any significant amount (1% to 5%) of merchantable timber encountered. The loss of harvestable wood constitutes a significant reduction in the annual amount of wood that is available for use in the company's mills.

Wellsites, access roads, pipelines, etc. (which are linked to the development stage of the oil and gas scenario) have resulted in permanent deletions from the forest management area in the amount of 9,000 acres during the same time.

Only quite recently have agreements been finalized between St. Regis (Alberta) Ltd. and the various oil companies that provide for salvage of a substantial amount of the merchantable timber contained within these permanent deletions. However, there still remain considerable losses in respect to the destruction of immature timber as well as the inherent reduction of our land base.

Possibly the most important, long-term irritant that the oil and gas development will impose on the forest industry is the segregation of its forest operating units by the hundreds of miles of pipelines. Due to safety hazards and government regulations, these pipelines cannot be traversed by heavy logging or site-preparation equipment. Consequently, each pipeline, whether it be a major export line or a simple gathering line, becomes an effective operational barrier around which the forest manager is forced to work and plan.

#### Conflicts Associated with the Existing Infrastructure

For administrative purposes, the forest management area is partitioned into five working circles. Each working circle is

further divided into several compartments with each compartment accomodating one age class or a group of similar age classes and is of a size which can accomodate harvesting over a 20-year period. These 20-year periods are termed "cutting cycles," thus, there are four cycles in the 80-year rotation under which we manage our forest management area.

The various compartments are further allocated to the four cutting cycles based on the actual age of timber contained within the compartments with the older or senior age classes of declining vigor having immediate priority. Since the first-cycle compartments are widely disseminated over the forest management area, this has meant that, in order to operate these compartments simultaneously, the total primary infrastructure of roads and supportive works had to be developed in the early stages of operations and have subsequently been utilized and maintained throughout the years.

With the concept of shared usage of such roads by other agencies, including the Alberta Forest Service, Department of Highways, and oil and gas companies as well as the general public, it is not difficult to imagine the irritation and incompatabilities that exist. Indeed, the latest surveys conducted on the major roads within our forest management area indicate that 60% of the total usage of these roads is, in fact, attributed to the oil and gas industry.

This type of heavy usage during all weather conditions (oil companies do not generally stop operations due to bad weather) considerably increases the maintenance costs associated with these roads and usually puts the holder of the forest management area in the distasteful position of "badgering" the other users for repair monies. Worse yet, the holder finds that the roads in question are suddenly unusable for its own operations.

As irksome as it may seem, the only other alternative would be to duplicate or parallel the existing extraction routes. This would have a further adverse effect on the forest land base as well as increase the number of operational barriers that now exist due to such things as pipelines, railroads, and high-voltage power lines.

#### Partial Solutions to the Above Problems

In order to minimize losses and inconveniences to our existing land base and infrastructure, St. Regis (Alberta) Ltd. has taken or is proposing to take the following steps:

1. Create a separate "land-use" section to deal exclusively with other user demands on our forest management area.
2. Implement an improved, land-base information-retrieval system that readily identifies existing and proposed infrastructure.
3. Provide supervision and/or manpower to salvage effectively an increasing amount of merchantable timber that would otherwise be lost due to the activities outlined above.

It should be understood however, that these steps will not, in themselves, provide a solution to the threat of the heavy development of nonrenewable resources. It is for this reason that St. Regis (Alberta) Ltd. now finds itself looking to the government of the province of Alberta for replacement lands that will be required for this company to meet its commitment of sustained-yield management and to otherwise remain a responsible, viable entity in its community.

## A NEW METHOD FOR IMPROVEMENT OF THE QUALITY OF *PINUS CONTORTA* SEEDS

Milan Simak

### INTRODUCTION

The precision sowing methods for production of forest plants, that is, the sowing of single seeds, demand seeds of the highest quality. However, in practice, a quantity of seed often contains, in addition to viable seeds, many that are dead or of low quality. These inferior seeds have to be removed before a precision sowing can be performed. A method, the so-called IDS method, for removing filled but dead seeds from a quantity of *Pinus silvestris* seeds was recently presented by Simak (1981). The method is based on the principle that viable seeds, after incubation and subsequent drying, lose absorbed water at a much slower rate than the dead seeds. This causes a distinct differentiation in weight and other physical properties between viable and dead seeds during a particular period of drying. These differences can be used for separation of the two types of seeds (fig. 1). Through removal of dead seeds, one can obtain a quantity of seeds which is virtually 100% germinable.

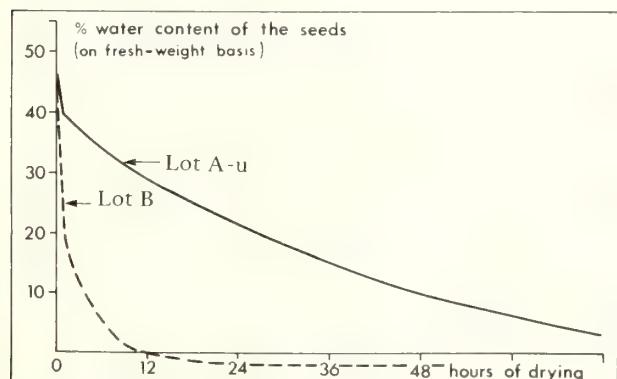


Figure 1. --The IDS principle.

The IDS method was also successfully applied on *Pinus contorta* seeds in laboratory and greenhouse experiments. Some of these results are presented here.

### MATERIALS AND METHODS

The laboratory and greenhouse experiments were carried out with a provenance of *Pinus contorta* seeds used in a reforestation program in Sweden. The low quality of the seeds would prohibit plant production in containers (table 1). Two seed lots of different quality (lot A = nearly all seeds viable, lot B = nearly all seeds dead) were laid out for germination at 15°C. Directly after 3 days incubation both lots contained approximately 45% water. No visible germination occurred during this incubation step. When the seeds were subsequently dried, the water evaporated faster from seed lot B than from seed lot A. Thus, after about 12 hours of drying, the weight of the seeds in lot B decreased to the value which they had prior to incubation (6-7%), whereas the viable seeds in seed lot A still contained approximately 30% water (see fig. 1).

Table 1--Description of the material. The percentage of the dead seeds was determined by a cutting test at the end of germination analysis.

Orig.	Lat.	Elev.	Imported to Sweden	Germination		Dead seeds	Mechan. damage
				7 days	21 days		
Teslin, Canada	60°10'	750m	1978	13	68	29	4

It follows then, that seeds in lots A and B, if mixed together, could be effectively separated from each other, after an incubation period and after about 12 hours drying, by flotation, gravity separation, or other methods. This method for removal of filled but dead seeds from a bulk sample is called the IDS method, according to the three main steps of the process: I = Incubation, D = Drying, S = Separation.

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The method can be modified for different species. For example, in the case of lodgepole pine, stratification of the seeds can be substituted for incubation (I step). After the stratification process, the seeds should be dried (D step) and separated (S step) according to the description above.

For separation of the seeds, these two alternatives of the IDS method were used and are outlined below:

a) IDS method (about 30g seeds were treated):

Incubation: 3 days between moistened blotters at +15°C, 100% RH, with light.

Drying: 12 hours at +15°C, 35% RH, with light.

Separation: Flotation in water. After about 5 minutes the buoyant seeds on the water surface were removed (dead seeds). The seeds on the bottom of the vessel were the viable seeds.

After-drying: After separation, the seeds were dried at +20°C to the moisture-content level which they had before their incubation (6-7%). The dried seeds were stored for several weeks at -5°C before being sown in the greenhouse experiment.

b) IsDS method (about 30g seeds were treated)

Incubation (Is): The seeds were stratified for 30 days at +4°C in a plastic bag. (The index "s" means stratification during the incubation step.)

Drying, separation, and after-drying: The same procedure as in the IDS method above.

The laboratory experiment was carried out on a Jacobsen's germinator at +20°C, 1,000 lux constant, over 21 days. Seeds were used at the rate of 3x100 seeds/treatment. The greenhouse experiment was carried out under conventional conditions for plant production used in Sweden. Seeds were sown in paper-pots with peat at 3x100 seeds/treatment.

## RESULTS

In the laboratory experiment, the germinability of the stratified (Is) as well as IDS-treated and IsDS-treated seeds from bottom ("viable") and surface fractions ("dead") was compared with that of the control seeds (fig. 2). Differences between the germination values of the control (C) and treatments were tested by a t-test.

In the greenhouse experiment, the germinability of the control seeds was compared with that of the stratified and IsDS-treated seeds (fig. 3).

## DISCUSSION

The experiments carried out in laboratory and greenhouse show that it is possible to effectively remove the filled but dead seeds from a sample by the IDS method. Using this method in combination with stratification (IsDS treatment), the improvement of the % germinability of the lodgepole pine seeds became so obvious that they may well be used for containerized plant production by single-seed sowing. Such a sowing method would of course be uneconomical using the untreated seeds, as it would result in as high as 34% empty containers. There is no technical hindrance to separating a large amount of seeds for practical use by the IDS method. However, the procedure has to

be adjusted for this purpose. Thus, the drying time can be cut down using higher temperature and lower RH%; the separation can be performed by other methods than by flotation water, etc. Technical equipment for this purpose is presently under

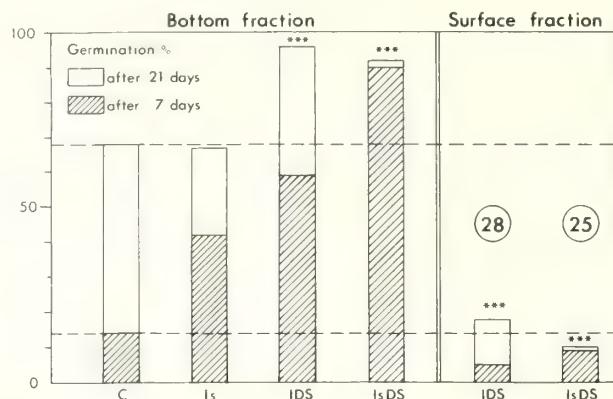


Figure 2. --Laboratory experiment. NOTE: The levels of significance: \* = 0.5, \*\* = 0.01 and \*\*\* = 0.001. The encircled figures indicate the percentages of seeds removed from the original sample during the separation (= surface fraction) NOTE: Is = Stratified, unseparated seeds showed a faster germination than the untreated control seeds. IDS = After removing the 28% of the seeds which proved to be dead from the sample, the germination capacity of the remaining seeds increased significantly. IsDS = By substituting the I step (3 day incubation) with the Is step (30 days stratification) and after removing the 25% dead seeds from the sample, nearly all remaining seeds germinated within 7 days. "Dead" seeds = The 18% and 10% germinated seeds of the surface fractions represent only 7% and 4% plants respectively, if recalculated for the total amount of plants produced in the IDS and IsDS treatment, respectively.

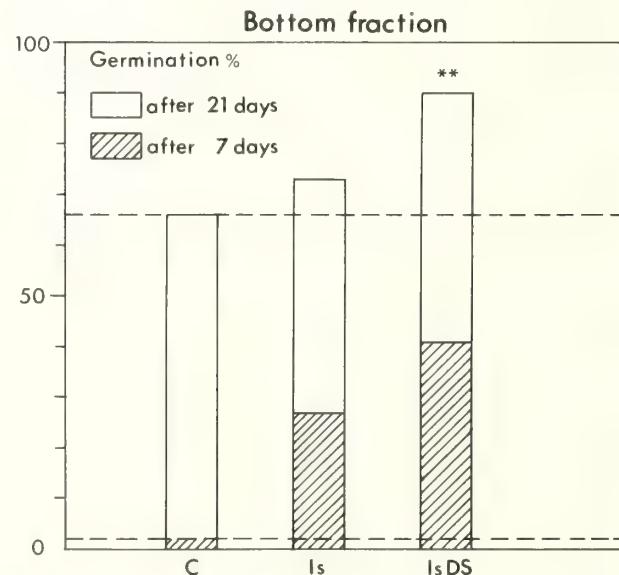


Figure 3. --Bottom fraction. For explanation of the figure, see figure 2. NOTE: Is = Stratified seeds germinate faster than the control seeds. An increase in the final germination was not expected, as the sample contained 29% dead seeds (cf. Material). IsDS: The germination after 7 and 21 days of the treated seeds was significantly better than that of the control seeds. For this considerable improvement of the seed quality, 4% of the plants were sacrificed. They were removed together with the "dead" seeds in the surface fraction.

development at our laboratory. A valuable aid in this connection is the x-radiography technique by which the IDS-procedure can be continuously checked on the treated seeds. An additional improvement of the germinability of the seeds used in the present experiments could be attained by removing the mechanically damaged seeds, which usually sink in the water to the bottom together with the viable seeds.

The positive effects of IDS and IsDS treatments which are presented in this paper were confirmed in several other experiments on seeds of *Pinus contorta*. The trials were carried out in different greenhouses and under various conditions. One of

the results is worth mentioning: the IDS-treated seeds can be stored for several months in containers or in a dry organic substrate such as peat without loss of the effects achieved through the treatment. This is, of course, of great advantage to nursery culture.

#### LITERATURE CITED

Simak, M. Bortsortering av matat-dott frö ur ett froparti. (Removal of filled-dead seeds from a seed bulk). Sveriges Skogsvårdsförbunds Tidskrift 5: 1981.

## POTENTIAL OF LODGEPOLE PINE AS A COMMERCIAL FOREST TREE SPECIES ON AN UPLAND SITE IN INTERIOR ALASKA

John N. Alden and John Zasada

### INTRODUCTION

Lodgepole pine, *Pinus contorta* Dougl. ex Loud., is one of more than ten exotic species from high latitudes with potential for management in interior Alaska. The natural range of lodgepole pine extends to about 110 kilometers of the Alaska-Yukon border at 64° north latitude (fig. 1). Seed sources from the northern range of lodgepole pine are well adapted to short growing seasons and the extreme cold of subarctic winters north of 60° latitude in Europe and western North America. Juvenile growth is rapid, and seed production is prolific and begins at an early age. Lodgepole pine is easily managed in short-rotation, even-aged stands, and genetic variation in desirable traits within and among provenances is extensive (Critchfield 1980). The extensive genetic variation provides versatility for adaptation of lodgepole pine to a wide range of habitats both within and outside of its natural range.

A wide-range provenance trial with twenty-nine lodgepole pine seed sources and one jack pine, *Pinus banksiana* Lamb., seed source within the range of jack X lodgepole pine hybridization was planted at the University of Alaska's T-field Arboretum at Fairbanks in June 1974 to evaluate the potential of lodgepole pine on a productive upland forest site typical of southern exposures in interior Alaska.

Differences among provenances in height growth, survival, and seed production after 10 years are reported here. The T-field plantation is the only provenance test in Alaska; and results have been used to sample lodgepole pine in Yukon and northern British Columbia for studying genetic variation in survival, growth, and reproductive success on a wide range of sites.

Before extensive provenance research is indicated, however, lodgepole pine must first be found to be more productive than

native conifers, and markets must be developed for small logs in Alaska.

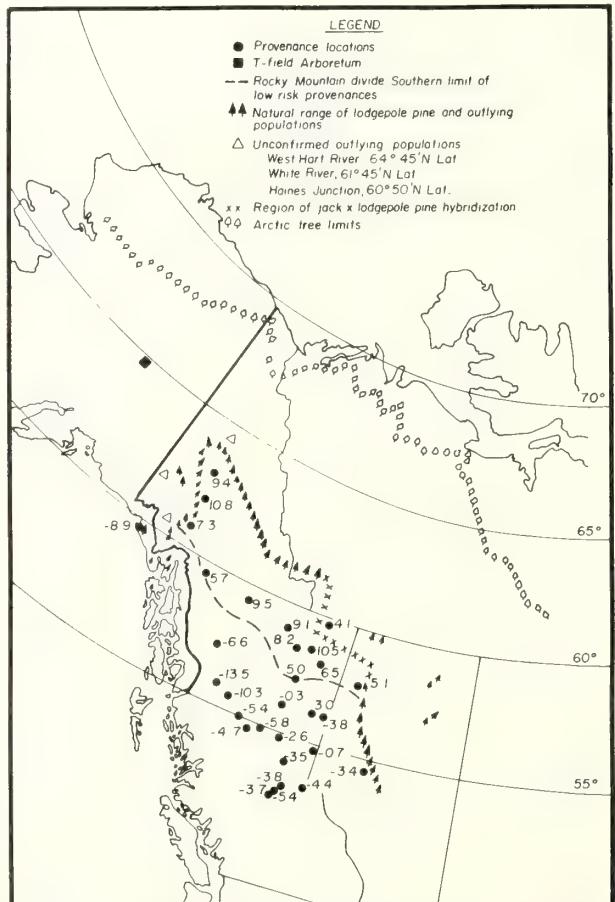


Figure 1.--Natural range of lodgepole pine at high latitudes and relative height growth index of 30 provenances at T-field Arboretum.

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## PROCEDURES

The lodgepole pine provenances trial was established at T-field Arboretum, Fairbanks, Alaska, in June 1974. The seedlings were supplied by Keith Illingworth, British Columbia Forestry Service, Victoria, B. C., and were planted as 2-1 bareroot stock grown at Red Rock Nursery, Prince George, B. C. Seed sources were from wide-range provenance collections in southeast Alaska, northern British Columbia, Yukon Territory, and Alberta (table 1). Two replications of nine tree plots for each provenance were planted 6 feet (1.8 meter) apart. Performance of outstanding provenances after seven growing seasons at the T-field is compared with earlier outplantings of lodgepole pine from Whitehorse, Yukon, approximately 60° 40'N latitude, 135° 30'W longitude, 750 meters in altitude; and Teslin Lake, Yukon, 60° 11'N latitude, 132° 43'W longitude, 825 meters in altitude; and jack pine from Fort Simpson, N. T., 61° 48'N latitude, 121° 18'W longitude, 150 meters in altitude. The earlier outplantings at the T-field Arboretum were made with 5-year-old seedlings from Whitehorse in September 1964 and 1-0 seedlings from Teslin and Fort Simpson in August 1966.

The climate at Fairbanks is continental subarctic with a mean annual temperature of -3.5°C and 275 mm of precipitation. Maximum rainfall occurs during summer and peaks at about 60 mm during August. The T-field Arboretum is located at 64° 52'N latitude, 147° 52'W longitude and 150 meters above sea level. The growing season produces about 1100 growing degree days<sup>1</sup> (C) and extends from mid-May to late August or early September.

<sup>1</sup> Growing degree days = Number of heat units, Celsius scale, above a mean daily temperature of 5°.

Table 1--Location, survival, growth, seed cone yields, and winter injury to thirty lodgepole pine provenances T-field Arboretum, Fairbanks, Alaska.

Plot Number	Provenance area	Latitude	Longitude	Altitude (meters)	1981 Survival, (percent)	1981 Height (cm)	Rank	Height <sup>2</sup> growth index	Winter <sup>3</sup> injury 1977-78, 79	# of cones per tree
19	Nithi R.	54° 03'	125° 05'	968	66	113	27	-4.7b	XX	-
21	Doris L.	54° 59'	126° 33'	960	84	131	23	-5.4b	XX	-
24	Finlay F.	55° 57'	123° 48'	686	84	176	16	-0.3b	XX	-
25	Hudson Hope	56° 02'	122° 05'	725	84	166	17	-3.0	XX	-
26	Tower L.	56° 01'	120° 37'	792	88	184	14	-3.8b	XX	0.1
27	Pink Mt.	57°	122° 24'	1112	100	209	12	5.0a	X	0.2
28	Tetsa R.	58° 40'	124° 10'	762	89	302	1	10.5a	X	8.8
29	Muncho L.	59° 03'	125° 46'	853	78	272	4	9.1a	-	8.0
32	Carmacks, Yukon	62° 14'	136° 18'	670	84	253	8	10.8a	-	9.1
33	Ethel L., Yukon	63° 18'	136° 28'	875	84	246	10	9.4a	-	8.0
34	Takhini R.	60° 41'	136° 11'	746	61	250	9	7.3a	-	3.8
35	Atlin	58° 48'	133° 47'	788	72	210	11	5.7a	X	3.2
36	Kinaskan	57° 29'	130° 13'	807	84	150	19	-6.6b	XX	-
37	Cassiar	59° 06'	129° 44'	792	84	264	5	9.5a	X	4.2
38	Jackfish Cr.	58° 32'	122° 42'	457	94	302	2	6.5	X	5.4
39	Redwillow R.	54° 56'	120° 15'	954	94	183	15	-0.7	XX	-
40	McLeod R.	54° 49'	122° 51'	697	100	148	21	-2.6	XX	0.2
62	McKale	53° 25'	120° 20'	701	76	116	26	-4.4b	XX	-
64	Wendle Park	53° 07'	121° 30'	1280	78	145	22	-3.7b	XX	-
65	Lynx L.	53° 39'	122° 58'	823	61	150	18	-3.5	XX	-
66	Stone Mt.	58° 39'	124° 46'	1173	89	257	6	8.2a	-	10.5
88	Yukutat, AK	59° 30'	139° 10'	45	67	51	30	-8.9b	XX	-
101	Kispiox	55° 38'	127° 54'	610	50	65	28	-10.3b	XX	-
102	Nass R.	55° 31'	128° 38'	305	39	52	29	-13.5b	XX	-
103	Kalder L.	54° 49'	124° 16'	945	100	148	20	-5.8b	XX	-
105	Bowron R.	53° 54'	122° 00'	671	78	126	24	-3.8b	XX	-
106	Wells	53° 08'	121° 33'	1112	73	123	25	-5.4b	XX	-
141	Hawk H., Alb.	57° 23'	117° 33'	716	100	257	7	5.1	X	0.7
142	Swan H., Alb.	54° 18'	116° 35'	823	84	187	13	-3.4	XX	0.3
163	Petittot R. <sup>1</sup>	59° 54'	122° 05'	396	89	291	3	4.1	-	9.4
				Mean	81	184				

<sup>1</sup> Jackpine. <sup>2</sup> Provenances with significantly faster (a) and slower (b) growth rates than the plantation average.

<sup>3</sup> - No apparent injury, X = Less than 10% of all trees injured, XX = 25 to 100% of all trees injured.

Height growth, survival, and winter injury were recorded annually from 1975 to 1981 for the provenance study. Pollen and seed-cone production was recorded for all outplantings in 1981. Two cones were collected at random from each of four seed-producing trees per provenance (two per replication) in October 1981. The cones were air-dried overnight at 58°C, and the seed was extracted, x-rayed, and germinated at room temperature to evaluate viable seed production. Data used to compare differences among species, provenances, and outplantings were either transformed to normal distribution before statistical analysis or analyzed by nonparametric methods.

## RESULTS

### Height Growth

Height growth of all outplantings increased exponentially during the first 7 years after outplanting. Mean height of the provenance trial and two superior provenances was 1.84 and 3.02 meters, respectively (table 1). Differences among provenances in 1980 and 1981 were highly significant at less than .001 probability of type I error. Mean height growth of the best twelve provenances was 2.59 meters. Height growth rates of Teslin and Whitehorse, Yukon, provenances after fourteen and sixteen growing seasons, respectively, are 0.7 and 0.8 meters which indicate that the superior provenances will continue to grow rapidly at least until crowns close at 12 and 15 years of age. The superior provenances are expected to average 9 meters in height at 15 years of age although they were inferior in height 1 year after outplanting (fig. 2). Growth rates for 3 to 5 years after outplanting reflect seedling age and size differences at planting and reaction of the provenances to change from nursery to plantation environments.

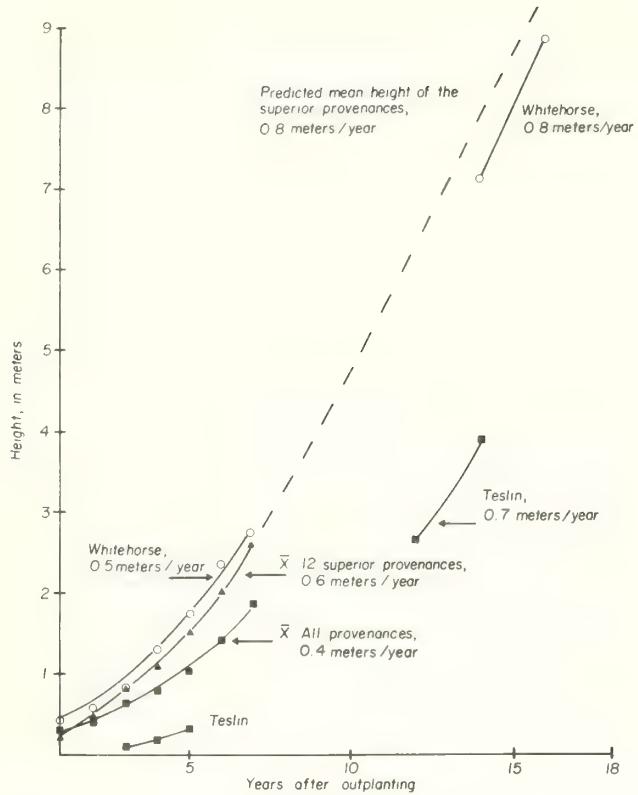


Figure 2.--Actual and predicted height growth of the 12 superior provenances and actual growth of 14- and 16-year-old lodgepole outplantings at T-field Arboretum. Lines are fitted curves. Symbols along lines are observed values.

A relative height growth index (HGI) for predicting early provenance performance was determined from a simple regression of mean annual provenance height as a percentage of mean plantation height on years of plantation development:

$$y = a + b_1 x$$

where

$y = \bar{x}$  provenance height/ $\bar{x}$  plantation height

$x =$  number of growing seasons after outplanting

$b_1 =$  height growth index (regression coefficient).

Height growth index is the change in provenance height relative to the plantation mean height per unit of time. Provenances with positive HGIs are growing faster than the plantation mean.

HGIs of the twelve superior provenances averaged 7.6 after seven growing seasons at T-field Arboretum. These provenances are located in the Yukon River, Liard River, and lower Peace River drainages. Provenances located in the upper Peace River region and rivers flowing southwest into the Pacific Ocean averaged -5.0 HGI. The Rocky Mountains divide that separates rivers flowing north and southwest is apparently the southern limit of lodgepole pine provenances that grow well on typical southern exposures in interior Alaska (fig. 1). High-altitude provenances at Wendl Park (1280 meters) and Wells (1112 meters), B. C., south of this divide, also grew slower than the plantation mean. Experiments in Sweden indicate that periods and rates of lodgepole pine growth are more closely related to latitude than altitude of seed source (Hagner 1970).

Growth rates (HGIs) of all fast-growing provenances except Jackfish Creek south of Fort Nelson, B. C.; Hawk Hills, Alberta; and jack pine on Petittot River, B. C., were significantly greater than the plantation mean (table 1). Provenances with large HGIs that lack significant departure from the plantation mean have variable growth rates. Although the lodgepole pine, Jackfish, provenance (#38) and the jack pine, Petittot R., provenance (#163) are among the three tallest after seven growing seasons, their relative growth rate is variable and declining (fig. 3). HGIs of the northern Yukon Territory provenances, on the other hand, show continued improvement and are more stable. These provenances may be superior after 1985, while most trees in provenances with negative HGIs will undoubtedly succumb to environmental extremes and competition from adapted neighbors (photo 1).

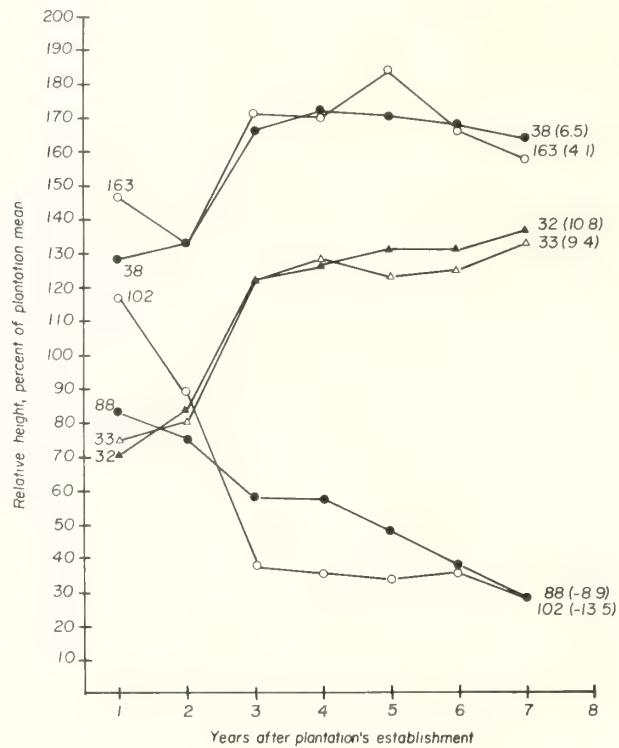


Figure 3.--Relative performance and height growth index of the tallest (38, 163), highest latitude (32, 33), and least adapted (88, 102) provenances.

#### Survival and Winter Injury

Eighty-one per cent of all trees in the provenance study survived seven growing seasons after outplanting. Average survival ranged from 39% for Nass River, B. C., 55°21'N latitude, to 100% for Mcleod River, 54°49'N latitude; Pink Mountain, B. C. 57°N latitude; and Hawk Hills, Alberta 57°32'N latitude. Average survival of the superior provenances did not exceed the plantation average until 3 years (1977) after outplanting (fig. 4). Number of replications and trees per provenance are too few for testing hypotheses concerning survival differences among provenances. For this reason, average mortality rates for the plantation and superior provenances were compared. Predicted mortality rates from environmental extremes, e.g., winter injury, are only 1.9% per year for all provenances and 1.0% per year for the twelve superior provenances (fig. 4). This difference is highly significant and indicates that survival will be truly different among provenances in time.



Photo 1.--Excellent height growth of the Ethel Lake, Yukon Territory provenance,  $63^{\circ}18'N$ . Lat. at T-field Arboretum (HGI=9.4). The two outstanding trees in the background averaged 3.2 meters in height after seven growing seasons. The provenance in the foreground is Nithi River, British Columbia,  $54^{\circ}03'N$ . Lat. (HGI=4.7). The center tree is 1.6 meters in height. Terminal shoots failed to elongate after severe winter injury in 1981-82. The trees were photographed on 7/30/82.

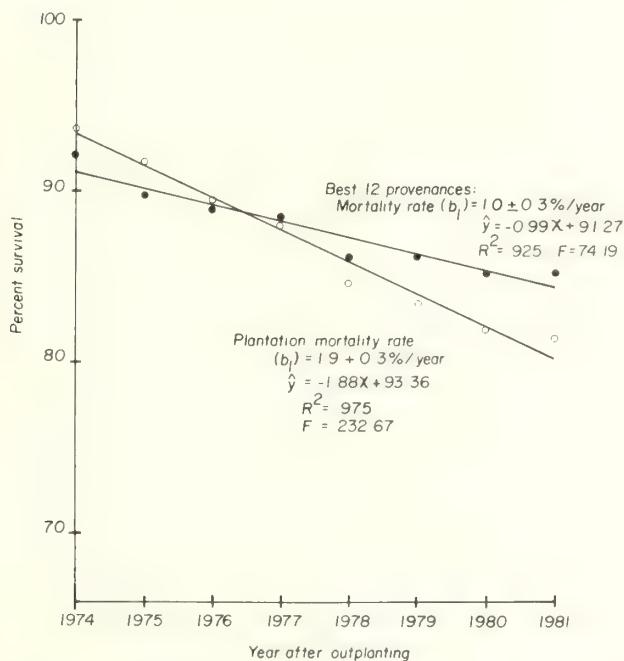


Figure 4.--Predicted mortality rates for the T-field provenance study and 12 superior provenances. Differences in mortality rates are significant at less than 0.05 probability of Type I error.

All provenances from Yukon and three provenances from northeast British Columbia escaped winter injury in 1977-78 and 1978-79 (table 1). More than 90% of the trees among the remaining six fast-growing provenances escaped apparent winter injury while 25 to 100% of the trees in provenances south of the Rocky Mountain crest in northern British Columbia were injured. Provenances south of this general area are apparently highly susceptible to winter injury on pro-

ductive southern exposures in interior Alaska. The Whitehorse, Yukon, provenance was also injured in 1966, 2 years after outplanting. Thus, even northern provenances present some risk of winter injury, and parents should be carefully screened before their progenies are widely outplanted.

Time of injury was not determined; but brown needles and dead buds and twigs apparent in late spring suggest that high-risk provenances lose hardiness in early spring and become susceptible to late frosts.

#### Seed Production

Sixty-one of the trees in the eleven tallest provenances produced seed cones, and 59% of the trees produced pollen cones in seven growing seasons after outplanting. Number of seed cones and clusters of male strobili averaged 6.3 and 24.9 per tree. Only the number of male clusters was significantly different among provenances (table 2). Jack pine and lodgepole pine provenances near the range of hybridization in northeast British Columbia produced more male strobili than the two northern provenances in Yukon and Hawk Hills in Alberta. Atlin, B. C., at the southwest limit of low-risk provenances produced only 1.7 male clusters per tree. Pink Mountain, B. C., and the eighteen slow-growing, high-risk provenances produced from 0 to 0.3 cones per tree each (table 1) and could not be sampled for seed analysis.

Only 7.8 fully developed and 5.5 filled seed were recovered from an average of thirty-six seed-bearing scales per cone in the provenance trial. Differences among provenances in total seed yield and seed-bearing scales per cone were not significant, but filled seed yields differed significantly. Filled seed germination averaged 88.2% for jack pine and 99.2% for all lodgepole pine provenances after 10 days of cold stratification and 14 days at room temperature ( $23^{\circ}\text{C}$ ).

Low pollen production, timing of dehiscence and receptivity of male and female cones, and variation in pollen dissemination undoubtedly contribute to poor seed recovery from young trees. Cone production, total seed yield, and filled seed yield per cone increased significantly with tree and plantation age. These results are summarized in table 3 with an estimation of seed production of lodgepole pine from northern provinces on a warm site in interior Alaska.

#### Applying Results of the T-Field Arboretum Provenance Study

Interior and southcentral Alaska contain 43 million hectares of forest land of which only 9 million hectares is currently producing commercial quantities of wood<sup>1</sup> (Hutchinson 1967). Many areas are occupied by slow-growing noncommercial tree, shrub, and grass species. These species produce deep organic layers that insulate underlying soils causing permafrost and poor soil drainage. The productivity of forest area in Alaska can be substantially increased with site preparation, introduction of rapid growing tree species such as lodgepole pine, and maintaining optimum stocking levels through applied management practices.

Large quantities of *Pinus* pollen found in pre-Wisconsin strata of eastern Alaska indicate that lodgepole pine may have been a major component of forests west and north of its present range more than 80,000 years ago (Matthews 1970). However, lodgepole pine macrofossils have not been discovered in Alaska

<sup>1</sup> Forests producing less than  $1.4 \text{ m}^3$  of wood per hectare per year are considered noncommercial in Alaska.

Table 2--Average number of pollen strobili clusters per tree for the eleven fastest growing lodgepole pine provenances in T-field Arboretum.

Provenance	Provenance Number	Average number of seed cones per tree	Average number of pollen cluster per tree*
Atlin, B. C.	35	3.7	1.7
Ethel Lake, Yukon	33	8.0	15.5
Hawk Hills, Alb.	141	0.7	15.5
Carmacks, Yukon	32	9.1	15.8
Cassiar, Yukon	37	4.2	17.0
Takhini River, Yukon	34	3.8	19.4
Jackfish Creek, B. C.	38	5.4	29.3
Tetsa River, B. C.	28	8.8	31.7
Stone Mt., B. C.	66	10.5	32.4
Muncho Lake, B. C.	29	8.0	37.0
Petittot River, B. C. (jack pine)	163	9.4	52.0

\*Provenances enclosed by a common line are not significantly different at .05 probability or less of type I error as determined by non-parametric multiple comparisons using the Mann-Whitney U-test statistic (Sokal and Rohlf, 1969, pp. 388-397).

Table 3--Biennial seed production for northern jack and lodgepole provenances at T-field Arboretum. Estimates are from age-related differences in cone and seed yields.

Species	Provenance	Age in years		Yields					
		Trees	Plantation	Cones/tree <sup>1</sup>	Filled seeds/cone <sup>1</sup>	Trees/hectare	Seeds/hectare	Grams/1000 seed <sup>1</sup>	Kilograms/hectare
Jack pine	Petittot River, B. C.	10	7	20.9 ab	2.8 a	2000	$1.2 \times 10^5$	3.37 ab	0.4
Jack pine	Fort Simpson, N. T.	15	15	38.7 bc	17.2 b	1000	$6.7 \times 10^5$	3.91 ab	2.6
Lodgepole pine	Northern B. C., Yukon	10	7	6.3 a	6.2 a	2000	$7.8 \times 10^4$	4.10 b	0.3
Lodgepole pine	Teslin, Yukon	15	15	15.9 ab	24.9 b	1000	$4.0 \times 10^5$	3.00 a	1.2
Lodgepole pine	Whitehorse, Yukon	23	17	88.1 c	22.8 b	625	$1.3 \times 10^6$	3.52 ab	4.6

<sup>1</sup>Values with a common letter are not significantly different at .05 probability or less of a type I error as determined by the Student-Newman-Keuls multiple-range comparison procedure (Sokal and Rohlf, 1969, p. 239).

and east-prevailing winds often deposit *Pinus* pollen from Canadian forests over a wide area beyond present Arctic tree limits in the Brooks Range (Walker et al. 1981). Thus, evidence that the range of lodgepole pine extended west of about 143° longitude in recent geological time is lacking. Nevertheless, results of the T-field provenance trial show that lodgepole pine from the northern part of its range is winter resistant and grows rapidly at a warm upland site in interior Alaska.

The ability of Yukon populations to develop early winter resistance while maintaining a long growing season is unique. Northern and western populations develop high winter resistance without early lignification of phloem cells (Hagner 1970). The latter trait is characteristic of shore pine, variety 'Contorta' (von Rudloff and Nyland 1979). Recent electrophoresis analysis of polymorphism in wide-range, lodgepole pine collections provides evidence that populations from Yukon and northern British Columbia had different refugia than southern populations during the Wisconsin glaciation (Wheeler and Guries 1982). These studies suggest that the Rocky Mountain summit in northern British Columbia is a greater barrier to migration of lodgepole pine after Pleistocene glaciations than are the coastal mountains of southeast Alaska and northeastern British Columbia. Coastal populations are more variable genetically than interior populations (Wheeler and Guries 1982) and may produce greater change in population structure of lodgepole pine in Yukon refugia as a result of natural selection during Pleistocene interglacial migrations and introgressions.

Although lodgepole pine is of commercial importance worldwide, its natural range north of 60° latitude is largely unknown. Most northern populations in Yukon Territory are small, isolated stands that are less than 100 years of age. These populations are incapable of competing with more-tolerant black spruce, *Picea mariana* (Mill.) B. S. P., especially on permafrost

sites and in the absence of fire. Results of the T-field provenance study indicate that only the northern range of lodgepole pine may contribute substantially to the genetic base introduced into interior Alaska and perhaps other high-latitude countries. An international effort to locate and sample the northern populations for provenance research and gene-pool conservation should be considered.

#### Plans for Evaluating Lodgepole Pine in Alaska

Two hundred and twenty-five unrelated, open-pollinated families from approximately fifteen provenances in the low-risk region of figure 1 have been collected and mapped for provenance research in interior Alaska. Stands within provenances were sampled with at least two families each where stand differences were apparent. Additional provenances from northwest and coastal British Columbia will be evaluated in the maritime climate of Kenai Peninsula and southcentral Alaska. Plans are to randomize each provenance, family within provenance, and trees within family in four to six replications per plantation within provenance test regions. This design will allow us to evaluate all sources of genetic variation in lodgepole pine on a range of sites within each provenance test region. Provenance test regions have been delineated by grouping locations with similar climatic factors that affect tree growth, e.g., growing degree days, dates of early and late frosts, etc., with multivariate statistics. The provenance test regions will be modified into seed zones on the basis of provenance and family stability in survival and growth characteristics for several test sites and dates of establishment. The test plantations will also provide a source of genetic material for selecting future breeding populations adapted to seasonal climatic extremes, pests, and soil characteristics of each seed zone.

The number of seed zones and breeding populations will depend on how well provenances and families are adapted to the wide range of site conditions in Alaska. Future tree-breeding and improvement strategies should be designed to incorporate rapidly growing families into breeding and seed-producing populations for each seed zone. These strategies will maintain a broad genetic base for adaptation of lodgepole pine to environmental change in time and among sites.

#### Potential Risk of Lodgepole Pine Management in Alaska

Mammals that feed on woody tissues in winter, including hares, moose, voles, and squirrels, pose the greatest immediate threat to introduction of lodgepole pine in Alaska. Small mammals are serious pests. Snowshoe hares girdle the stems and clip branches of young seedlings. Hare populations fluctuate from 0.1 to 6 animals per hectare in 10-year cycles in interior Alaska (Wolff 1980). Severe losses can be expected where alternating dense and open habitats favor population buildups. Voles frequently cause large losses during the winter in young Swedish plantations (Hagner and Fahlroth, 1974). Local populations of the taiga vole reach 100 animals per hectare for 10- to 20-year periods in interior Alaska (Wolff and Lidicker 1980). The taiga vole obtains 10 per cent of its winter diet by foraging away from food stored in nesting areas. Red squirrels feed on the phloem of young lodgepole pine when other sources of food are unavailable. Red squirrel populations average about 2.5 animals per hectare in Alaska but they are not considered serious threats because mature forests are preferred habitats<sup>1</sup>.

Moose populations seldom exceed one animal per square kilometer in interior Alaska but local concentrations may reach eight to twelve animals per square kilometer in winter.<sup>2</sup> Each animal consumes about 18 kilograms of fresh browse per day and may cause severe damage in wintering areas where lodgepole pine is the only major nutrient available. The range or population densities of caribou and buffalo are presently more limited than moose in Alaska, and these animals should pose no serious threat to lodgepole pine management.

The rust fungi are a second group of potential pests of lodgepole pine in Alaska. Alternate hosts of sweetfern blister rust, *Cronartium comptoniae* Arth. (*Myrica gale* and *Comptonia* spp.), and stalactiform rust, *Peridermium stalactiforme* Arth. and Kern (*Castilleja* and *Melampyrum* spp.), serious diseases of lodgepole pine, are widely distributed in Alaska (Hultén 1968). The western gall rust, *Peridermium harknessii* Moore, does not require an alternate host to complete its life cycle. Mesic summers of interior Alaska could enhance inoculum buildup and widespread infection of the rusts. The comandra rust, *Cronartium comandrae* Peck, is the only serious rust pathogen that does not have alternate hosts in Alaska and presents no impeding threat to management of lodgepole pine. A small population of the alternate host, bastard toad flax, *Comandra umbellata* (L.) Nutt., survives at Steward Crossing, Yukon (Hultén 1968), however.

The rust fungi are not as widespread and infections are not as severe in the northern range of the lodgepole pine, but northern populations are more susceptible to infection when they are transferred south than are southern populations (Martinsson 1980, British Columbia Forest Research Review 1979-80).

Root systems of lodgepole pine, especially trees grown from containerized seedlings, are unstable in fine textured soils (Martinsson 1982). Plantations grown on silt-loam loess soils of interior Alaska may be susceptible to windthrow in regions where high winds are prevalent.

#### CONCLUSIONS

The potential of lodgepole pine as a commercial species in Alaska is revealed by the rapid juvenile growth and winter resistance of northern provenances at the T-field Arboretum. Short-rotation yields of provenances from the Yukon and Liard River Watersheds may compare favorably with many commercial species in temperate forests of southern Canada and the United States in spite of potential pest problems. Support for provenance research is necessary to discover superior genetic sources of lodgepole pine and to evaluate their productivity on a wide range of sites in interior and southcentral Alaska. The future of lodgepole pine in Alaska will depend on how well it competes with native white spruce, *Picea glauca* (Moench) Voss, and other exotic species, the effectiveness of provenance introduction and tree-improvement strategies, and development of a small-log market for high-latitude forests in North America.

#### Acknowledgments

The foresight and effort of Dr. Les Viereck, Institute of Northern Forestry, in establishing the early lodgepole pine outplantings at the T-field Arboretum are appreciated. Special recognition is extended to Susan Brooks, graduate student, University of Alaska, for assistance in collecting and summarizing the growth and seed-yield data.

#### LITERATURE CITED

- British Columbia Forest Research Review. Victoria, B. C.: Ministry of Forests and Research Branch; 1979-1980. 59 p.
- Critchfield, W. B. The genetics of lodgepole pine. Washington, D. C.: USDA For. Serv. Res. Pap. WO-37; 1980. 57 p.
- Hagner, Mats. A genecological investigation of the annual rhythm of *Pinus contorta* Dougl. and a comparison with *Pinus sylvestris* L. Studia Forestalia Suecica. No. 81; 1970. 26 p.
- Hagner, Stig; Fahlroth, Siggardt. [On the prospects of cultivating *Pinus contorta* in Norway] Sveriges Skogsvårdförbunds Tidskrift 72: 477-528 [Eng. summary]; 1974.
- Hultén, Eric. Flora of Alaska and Neighboring Territories. A manual of the vascular plants. Stanford, CA: Stanford University Press; 1968. 1008 p.
- Hutchinson, O. K. Alaska's Forest Resource. USDA For. Serv. Res. Bull. PNW 19. Portland, OR: PNW For. and Range Exp. Stn.; 1967. 74 p.
- Martinsson, Owe. Stem rusts in lodgepole pine provenance trials. Silvae Genetica 29: 23-26; 1980.
- \_\_\_\_\_. [Root development and stability of lodgepole pine]. Sveriges Skogsvårdförbunds Tidskrift (1-2) 1-94 [Eng. summary]; 1982.
- Matthews, John V., Jr. Quaternary environmental history of interior Alaska: Pollen samples from organic colluvium and peats. Arctic and Alpine Res, 2(4): 241-251; 1970.
- Sokal, Robert.; Rohlf, F. James. Biometry. San Francisco, CA: W. H. Freeman Company; 1969. 776 p.
- von Rudloff, E.; Nyland, E. Chemosystematic studies in the genus pinus. III. The leafoil terpene composition of lodgepole pine from Yukon Territory. Can. Jour. of Bot. 57(12): 1367-1370; 1979.
- Walker, D. A.; Short, S. K.; Andrews, J. T.; Webber, P. J. Late holocene pollen and present-day vegetation, Prudhoe Bay

<sup>1</sup>Mowrey, R. A. 1982. Personal communication. INF, Fairbanks.

<sup>2</sup>Van Ballenberghe, V. 1982. Personal communication. INF, Fairbanks.

- and Atigun River, Alaska North Slope. Arctic and Alpine Research 13(2): 153-172; 1981.
- Wheeler, N. C.; Guries, R. P. Biogeography of lodgepole pine. Can. Jour. of Bot. 60(9): 1805-1814; 1982.
- Wolff, Jerry O. The role of habitat patchiness in the population dynamics of snowshoe hares. Ecological Monographs 50(1): 111-130; 1980.
- Wolff, J. O.; Lideke, W. Z., Jr. Population ecology of the taiga vole, *Microtus xanthognathus* in interior Alaska. Can. Jour. of Zool: 4800-1812; 1980.

## LODGEPOLE PINE IN THE SWEDISH REFORESTATION – PROBLEMS AND PROSPECTS

Owe Martinsson

### INTRODUCTION

Lodgepole pine has been used in Swedish forestry since the end of the 1960s. Small, experimental plots of this tree species were already established at the beginning of this century.

During the past few years, about 50 million seedlings have been planted annually; this is approximately 10% of the total nursery stock. The total area of lodgepole pine plantations in Sweden today covers 180,000 hectares (Nellbeck 1982, Hagner 1982); 30% of this area was planted in 1980 and 1981. Lodgepole pine is used by the forest companies primarily in the northern part of the country. It is being substituted for Scots pine and is used mainly on poor sites at relatively high altitudes. The primary reasons for introducing lodgepole pine are:

- Its superior volume production. Compared to Scots pine on equivalent site class, lodgepole pine is expected to produce 40–60% more wood per hectare.
- Because of the rapid growth and a shorter rotation period, lodgepole pine is expected to reduce the significant wood shortage anticipated in Sweden in about 40 years.

Two more conditions speak in favor of lodgepole pine:

- There is a lack of Scots pine seed for the most northern part of Sweden, and
- Logdepole pine has shown a better resistance to some of the most common diseases of Scots pine.

### The seed demand

The lodgepole pine seed supply has so far been entirely imported from Canada. About 600 kg of seed has been imported annually during the last years. Some 30 hectares of seed orchards of lodgepole pine were established in the beginning of the 1970s. In 1977, a coordinated project was started to meet the future Swedish demand for lodgepole pine seed. Seed lots were collected from twelve selected trees from fifteen stands in each of

six seed regions in B. C., western Alberta, and up to the northern limit of distribution in Yukon. Together with earlier collections, we now have progenies from more than 1,300 selected trees. Based on this materials, another 80 hectares of seed orchards are being established. When they are in full production, we expect to harvest about 400 kg per year (Rosvall 1982).

### Establishment

The most common method for establishing lodgepole pine stands has been planting 1-year-old containerized seedlings with 2x2-m spacing, i.e. the same as that used for Scots pine. The seedlings' growth is very rapid and the lodgepole pine plantations are generally better in terms of survival and growth than plantations of native tree species, despite the fact that lodgepole pine is commonly used in areas with harsher climate.

### VOLES AND STABILITY—THE TWO MAIN PROBLEMS

The two main problems we have seen so far are attacks of voles in young stands and instability of the trees against snow and wind pressure. Lodgepole pine is more frequently attacked by voles than our native pine (Hansson and Lavsund 1982). A useful property of the lodgepole pine is, however, its ability to survive and recover even after serious attacks. In provenance trials we have also observed that some northern provenances are attacked less than others, a situation which could eventually provide some information useful in controlling the animals (Karlman 1982). The damage also seems to be less serious in depressions and north slopes than in wind-exposed south and west slopes.

The lack of stability against wind and snow pressure is not due primarily to bad root development but to the relationship between the root and the shoot (Martinsson 1982b, Martinsson and Lundh 1982). Especially when planted as a containerized seedling, the young tree produces heavy, wide branches, and the relationship between the root and crown becomes very detrimental to stability. I think that this might be a consequence of the wide spacing and the rapid growth. In natural growing conditions, the spacing is very close, and the extension of the

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crown is reduced by competition for light. The distribution of the root is not limited in the same way. In the Swedish stands, the stability is further reduced in winter when the wide crown with its long needles collects wet snow and sometimes ice. In that situation the tree falls over easily. In contrast to the root system of Scots pine, that of the lodgepole pine is more concentrated and has a greater proportion of thin roots, which probably means a more efficacious uptake of nutrients and rapid growth, but the stability of the tree would probably have been favored by thicker roots with a wider extension (figs. 1-4).

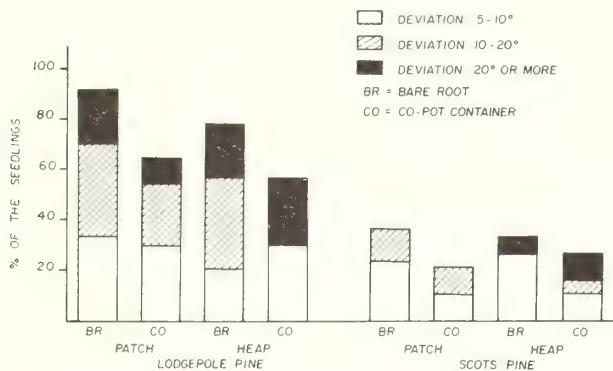


Figure 1.--Basal sweeps.

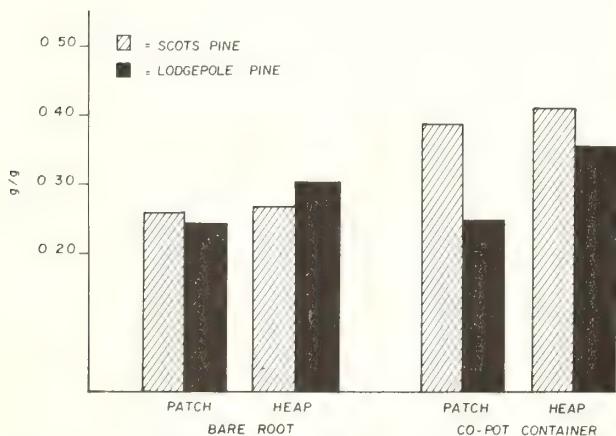


Figure 2. --Root weight/crown weight.

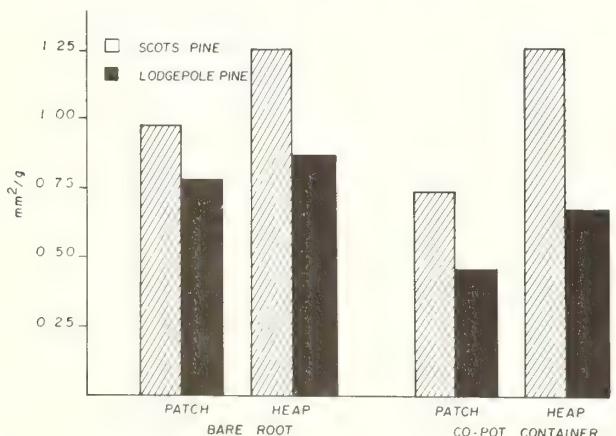


Figure 3. --Root area/crown weight.

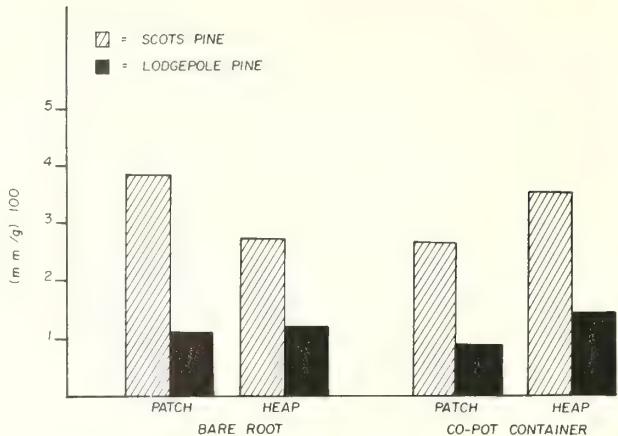


Figure 4. --Average root diameter/crown weight.

The seedling container used in the nursery has a lengthy negative influence after the planting of the seedling in the field. The roots are deformed for several years and consist, to a large extent, of a central burl. In comparison to Scots pine and Norway spruce of similar size, the lodgepole pine roots have a bigger central burl and smaller lateral roots. Seedlings growing after direct seeding develop an almost ideal root form; that is, with no central burl and with stabilizing roots in vertical and horizontal directions. Direct seeding also gives a slower start to the seedling which improves the root/shoot relationship in young trees. As an adult tree, lodgepole pine may have developed a deep, heavy root system. In spite of that, it falls over easily, especially on windy sites or when the soil is fine textured.

#### PRODUCTION AND QUALITY

The evaluation of Swedish lodgepole pine forests is partly based on provenance trials established in the 1960s and 1970s and partly on 75 small experimental plots established between 1920 and 1935 in Finland and Sweden. The provenances used are generally from a more southern origin than is recommended today. Those older plots are generally smaller than 1 hectare, and in most cases are growing on above-average sites. The stands have been thinned several times.

Even though the provenances were not the most suitable, the average volume production exceeds that of Scots pine by 40-50%, depending on site quality class (Häggblom 1980) (fig. 5). The average annual increment reaches the maximum earlier on high-quality sites than on poor sites and earlier with a high number of stems per hectare than with a low number (fig. 6).

In the younger provenance trials, the investigations are not completed. Considerable differences in volume production between provenances are indicated however (Lindgren et al. 1980). In southern Sweden, the growth seems to be somewhat less in provenances originating from areas north of latitude 56°. In northern Sweden, provenances originating from areas north of latitude 62° are slower growing compared to provenances south of these latitudes. The survival of the trees increases with latitude of the provenance origin. The optimal combination of survival and growth in central and northern Sweden is therefore achieved in provenances from Yukon. However, the relationship between the latitude and the production properties in provenances of lodgepole pine is, in many cases, difficult to distinguish.

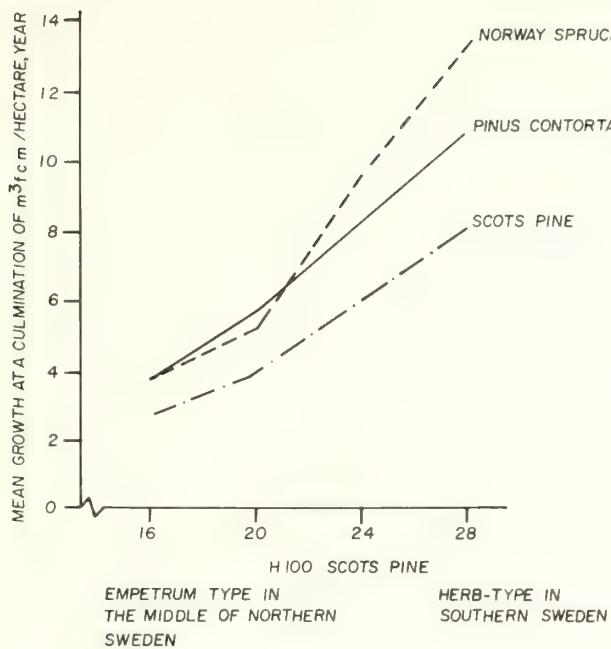


Figure 5.

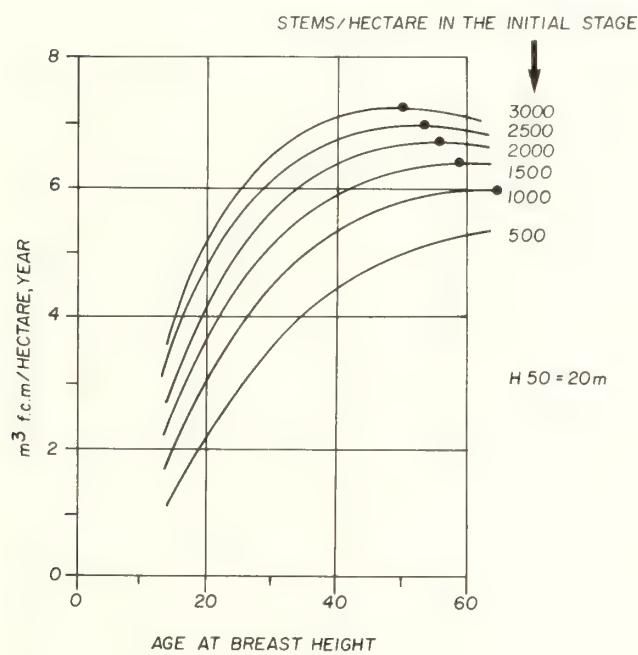


Figure 6. --Mean growth excluding natural thinning.

The properties of lodgepole pine make the wood useful for sawmill products as well as pulp and paper production. The quality of the boards produced is similar to board qualities of Scots pine grown in plantations (Andersson 1976). In order to achieve a good-quality board, it is necessary to use Scots pine grown through natural regeneration. The Swedish lodgepole pine will primarily be used in production of pulp and paper. Its wood properties for pulp and paper production are as good as or better than the properties of Scots pine. In addition, it can be used in processes other than those possible with Scots pine. The wood quality of lodgepole pine will probably be considerably improved through genetic breeding, which has not started yet (Persson 1982).

## DAMAGE FROM FUNGI AND INSECTS

Upon introduction of a new tree species, there are always risks that the introduced tree species will be damaged by indigenous or introduced insects and diseases. These risks are probably the most important reasons why precautions have to be taken. Within its native habitat, lodgepole pine is one of the most attacked tree species. The most serious diseases are caused by rust fungi closely related to European stem rust fungi. None of these North American rust fungi have yet been found outside the North American continent, even though natural conditions conducive to their propagation exist in Europe and Asia. If some of these fungi were transferred into Europe, a very dangerous situation would develop, since not only lodgepole pine but also Scots pine is susceptible to these diseases (Martinsson 1980). Scots pine has existed in northern Europe since the last glaciation, and none of the North American rust species have appeared so far. A natural spread without human participation, therefore, seems unlikely.

Damage from indigenous diseases on the Swedish lodgepole pine have so far been rather limited (Karlman 1981, Martinsson 1982a). The most common diseases from which our native tree species suffer have generally caused less damage on lodgepole pine. None of the European rust fungi, such as *Melampsora pinitorqua* or *Endocronartium pini*, seem to attack and damage lodgepole pine under field conditions. Needle diseases like snowblight (*Phacidium infestans*), pine needle cast (*Lophodermium sediticum*), or grey needle cast (*Lophodermella sulcigena*) have generally caused less damage on lodgepole pine than on Scots pine. Damage from root rot fungi such as *Heterobasidion annosum* and *Armillariella mellea* might appear as a problem. Lodgepole pine is, however, not intended to be used on sites where those diseases are prevalent.

With regard to insect pests, lodgepole pine is perhaps not so superior to Scots pine; but there is on the other hand no big reason to worry as yet (Eidmann 1982). About sixty species of insects have been observed on lodgepole pine in Sweden. Among the species which have caused damage, of practical importance are the large pine weevil (*Hylobius abietis*), the European pine sawfly (*Neodiprion sertifer*), the European pine shoot moth (*Rhyacionia bouliana*), the pine cone weevil (*Pissodes validirostris*), and the six-toothed pine beetle (*Pityogenes chalcographus*). The last-mentioned species has, in a few places, caused serious damage after cleaning in adjacent stands. Its ability to propagate seems to be limited in the stem of lodgepole pine, however.

## ECOLOGICAL QUESTIONS

Investigations on the influence of lodgepole pine on the forest flora, fauna, and soil conditions are in progress and only preliminary results exist. These indicate that the litter decomposition may be somewhat slower in a lodgepole pine stand than in a Scots pine stand. The pH value of the litter and the humus layer can be a little lower in a lodgepole pine stand. This could, however, be a direct consequence of the higher litter production in the lodgepole pine stand and it is not evident whether these differences have any practical impact on the soil condition (Lundmark et al. 1982).

## FUTURE RESEARCH ON LODGEPOLE PINE

The species *Pinus contorta* is and will remain a foreign tree species for a long time in Sweden. This means that the knowledge and experiences with this tree species is more restricted than with our indigenous trees. Research on lodgepole pine has to be pursued with a high intensity. The genetic research has

been most intensive. Other fields in which research is especially important include methods to minimize risks for ecological instability which may show up as damage from wind, snow, fungi, voles, and other animals. Another field which must be investigated is the suitability of lodgepole pine for different habitats. The silvicultural practices have to be better adapted to this tree species, and the economic impact for the regional and national forestry has to be analyzed.

#### LITERATURE CITED

- Andersson, E. *Pinus contorta*, sawability, permeability. Skogshöskolan, Inst f virkeslära, Rapport nr 99; 1976. 40 p.
- Eidmann, H.H. Insects on Lodgepole pine in Sweden. Sveriges skogsvårdsförb tidskrift 1-2/82; 1982: 59-64.
- Hagglund, B. Growth and yield in planted Lodgepole pine stands in Finland and Sweden. From *Pinus contorta* as an exotic species. Rapporter och uppsatser 30, Research Notes, Garpenberg; 1982: 167-181.
- Hagner, S. *Pinus contorta* and forestry management. Sveriges skogsvårdsförb tidskrift 1-2/82; 1982: 113-116.
- Hansson, L.; Lavsund, S. Damage by vertebrates to *Pinus contorta* plantations. Sveriges skogsvårdsförb tidskrift 1-2/82; 1982: 65-71.
- Karlman, M. The introduction of exotic tree species with special reference to *Pinus contorta* in northern Sweden. Review and background. Studia For Suec 158; 1982. 25 p.
- \_\_\_\_\_. Damage to *Pinus contorta* within provenance trials. Sveriges skogsvårdsförb tidskrift, 1-2/82; 1982: 49-56.
- Lindgren, K.; Lindgren, D.; Persson, A. Survival and height increment of *Pinus contorta* IUFRO 70/71 series in Sweden. Form *Pinus contorta* as an exotic species. Rapporter och uppsatser 30, Research Notes, Garpenberg; 1980: 103-135.
- Lundmark, J-E; Berg, B.; Nilsson, Å. The influence of *Pinus contorta* on the soil and ground vegetation in comparison with *Pinus sylvestris*. Sveriges skogsvårdsförb tidskrift 1-2/82; 1982: 43-48.
- Martinsson, O. How dangerous are the North American pathogens to the Scandinavian lodgepole pine? From *Pinus contorta* as an exotic species. Rapporter och uppsatser 30, Research Notes, Garpenberg; 1980: 257-263.
- \_\_\_\_\_. Pathogenic fungi on Lodgepole Pine. Sveriges skogsvårdsförb tidskrift 1-2/82; 1982a: 57-58.
- \_\_\_\_\_. Root development and stability of lodgepole pine. Sveriges skogsvårdsförb tidskrift 1-2/82; 1982b: 91-94.
- Martinsson, O.; Lundh, J-E. Contortatallens rotstabilitet - proveniensens inflytande (English summary). Rapport nr 8, Inst för skogsprod, SLU, Garpenberg; 1982.
- Nellbeck, R. Why has Swedish forestry introduced contorta in Sweden? Sveriges skogsvårdsförb tidskrift 1-2/82; 1982: 17-20.
- Persson, A. The quality of *Pinus contorta* in comparison to Scots pine and Norway Spruce. Pulp, paper and saw timber. Sveriges skogsvårdsförb tidskrift 1-2/82; 1982: 37-42.
- Rosvall, O. Seed supply and seed orchard program for *Pinus contorta* in Sweden. Sveriges skogsvårdsförb tidskrift 1-2/82; 1982: 105-108.







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# Fuels and Fire in Land- Management Planning: Part 3. Costs and Losses for Management Options

Wayne G. Maxwell, David V. Sandberg,  
and Franklin R. Ward



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## Abstract

**Maxwell, Wayne G.; Sandberg, David V.; Ward, Franklin R.** Fuels and fire in land-management planning: Part 3. Costs and losses for management options. Gen. Tech. Rep. PNW-158. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 18 p.

An approach is illustrated for computing expected costs of fire protection; fuel treatment; fire suppression; damage values; and percent of area lost to wildfire for a management or rotation cycle. Input is derived from Part 1, a method for collecting and classifying the total fuel complex, and Part 2, a method for appraising and rating probable fire behavior. This approach can be used locally for fire management and in land-management planning.

**Keywords:** Fire management, fuels (forest fire), fire behavior (forest), fire planning, management planning (forest).

## Introduction

Land-management planning includes study of various use patterns and management intensities and alternatives. Evaluation of alternatives should address anticipated buildup of fuels that creates a wildfire hazard. Planning decisions affect potential for fire, which can either enhance or hinder achievement of management-planning goals. Land managers must consider both effects of fire and of alternative fire strategies (Egging and others 1980).

To judge among alternatives, planners need to know:

- What is the expected cost of fire protection?
- What is the expected cost of fuel treatment?
- What is the expected cost of wildfire suppression?
- What is the value of resource damage?

To supply reasonable answers, fire specialists need to know:

- Classification of fuel complexes in the planning area.
- Cost of fire protection associated with each fuel complex.
- Cost of fuel treatments associated with current management practices.
- Cost of suppression and value of damage for current wildfire losses.
- Number of acres usually damaged by wildfire under the existing fuel pattern.

The Pacific Northwest Forest and Range Experiment Station, in cooperation with the Pacific Northwest Region of the USDA Forest Service and the Siskiyou National Forest, initiated the Cal-Ore Pilot Test to develop techniques and procedures for meeting these needs. The study was on about 35,000 acres of the Illinois Valley Ranger District, Siskiyou National Forest, Oregon.

This is the final report of a three-part series. Part 1 (Maxwell and Ward 1981) describes a practical way to classify the total fuel complex. The objective for developing a fuel-classification system was to collect onsite fuel information from total drainage areas. To derive adequate answers for evaluating and projecting fire-behavior ratings and calculating costs and losses from wildfire, we recognized the need to describe all fuel components and link fuel type to land and vegetative types.

Part 2 (Maxwell and Sandberg, in review) describes a systematic means of using the fuel classification in Part 1 to appraise and rate probable fire behavior for local fuel conditions and construct fuel profiles and a fire-behavior map.

In Part 3, we show how the fire-behavior map and fire-behavior projections are used to produce:

- Costs of fire protection.
- Costs of fuel treatment.
- Costs of fire suppression and damage values.
- Percent of area lost to wildfire per management or rotation cycle.

Details are provided in this report on the steps accomplished in the pilot test:

- Summary of current fire-behavior potential.
- Summary and analysis of causes, extent, resource damage, and suppression costs of local wildfires.
- Development of a table of protection costs.
- Development of a table of fuel-treatment costs.
- Land-management plans and cost tables.

Also included are examples of:

- Management options.
- Projections of fire-behavior ratings.
- Projected costs of protection and fuel treatment.
- Projections of costs and losses from wildfire.
- Assembly of cost-loss projections.

This approach to computing the expected fire-management costs for various land-management alternatives differs from others that have been published in that site-specific fuel descriptions and fire-behavior estimates are used rather than stylized fuel models. It allows comparison of the costs of wildfire suppression with damage caused by alternative fuel treatments, but does not allow comparison of costs of changing fire-protection levels or suppression strategies.

## Summary of Current Fire-Behavior Potential

The fire-behavior map (fig. 1) developed from appraisal of local fuel beds in Part 2 was used to determine the percentage of the total area falling in each fire-behavior class by making a map dot grid count:

Fire-behavior class	Percent area in class
1	17
2	66
3	13
4	4

Seventeen percent of the area fell in fire-behavior classes 3 and 4, the crucial classes where more than initial attack or local forces are needed to control a wildfire and damage goes beyond "acceptable" losses and costs.

## Resource Damage and Suppression Costs of Local Wildfires

Statistics on acres burned and value of resource damage in the pilot-test area (part of Regional Planning Area V, which consists of the Rogue River, Siskiyou, and Umpqua National Forests) were derived using the Region 6 Fire History Program at the Fort Collins Computer Center for 1970 through 1979 (table 1). We believe these figures represent acres burned in the test area. The method can be used for any management unit, for example, USDA Forest Service Region, National Forest, or Ranger District.

Lightning-caused fires burned 0.00176 percent of the planning area annually; fires caused by industrial use burned 0.00931 percent and by general public use, 0.00581 percent. The average damage value from these fires was \$189 per acre (table 1). Cost of suppressing wildfire for the study area during the same period was \$2,197,567 to contain fires to 4,587 acres—about \$479 per acre.

Trends in historical data are used to project future prices and costs. Fundamental shifts in the forces of supply and demand as well as random events have affected historical data. Projections about the immediate future may be based on trends from the immediate past.

Unfortunately, data from the decade of the 1970's were affected by inflation (changes in the value of the dollar). Inflation is difficult or impossible to project from past trends. Therefore, data that are not corrected for inflation can seriously distort an economic analysis. For example, an item that cost \$1.00 in 1979 cost about \$0.50 in 1970. If the effect of inflation between 1970 and 1979 were removed, the real cost of the item would have been the same in both years. The analyst might assume that the real cost of what is purchased remains unchanged in the immediate future.

For short-range planning, land managers would like to know if costs in real (not inflated) dollars are increasing or decreasing and by how much. A two-step procedure can be used to project damage values and suppression costs. The first step is to remove effects of inflation from the historical data. To do this, actual damage and suppression costs from each year are multiplied by the appropriate adjustment factor shown in the third column of the following listing of Producer Price Index figures. The base year of our analysis is 1979. The third column is computed by dividing the Producer Price Index for 1979 by the index for each year. The Gross National Product Deflator could be used in place of the Producer Price Index.

Table 1—Region 6, area V (southwest Oregon) fire-statistics summary—acres burned<sup>1</sup> and dollar value of damage, 1970-79

	Causes of fires				Damage value
	Lightning	Industrial	Public use	Total	
- - - - - Acres - - - - -					
Total area burned	479	2529	1579	4587	868,000
Percent of total area protected	0.0176	0.0931	0.0581		Ā=189.27
Percent of area burned per year	0.00176	0.00931	0.00581		

<sup>1</sup>/Total acres protected = 2,717,490.

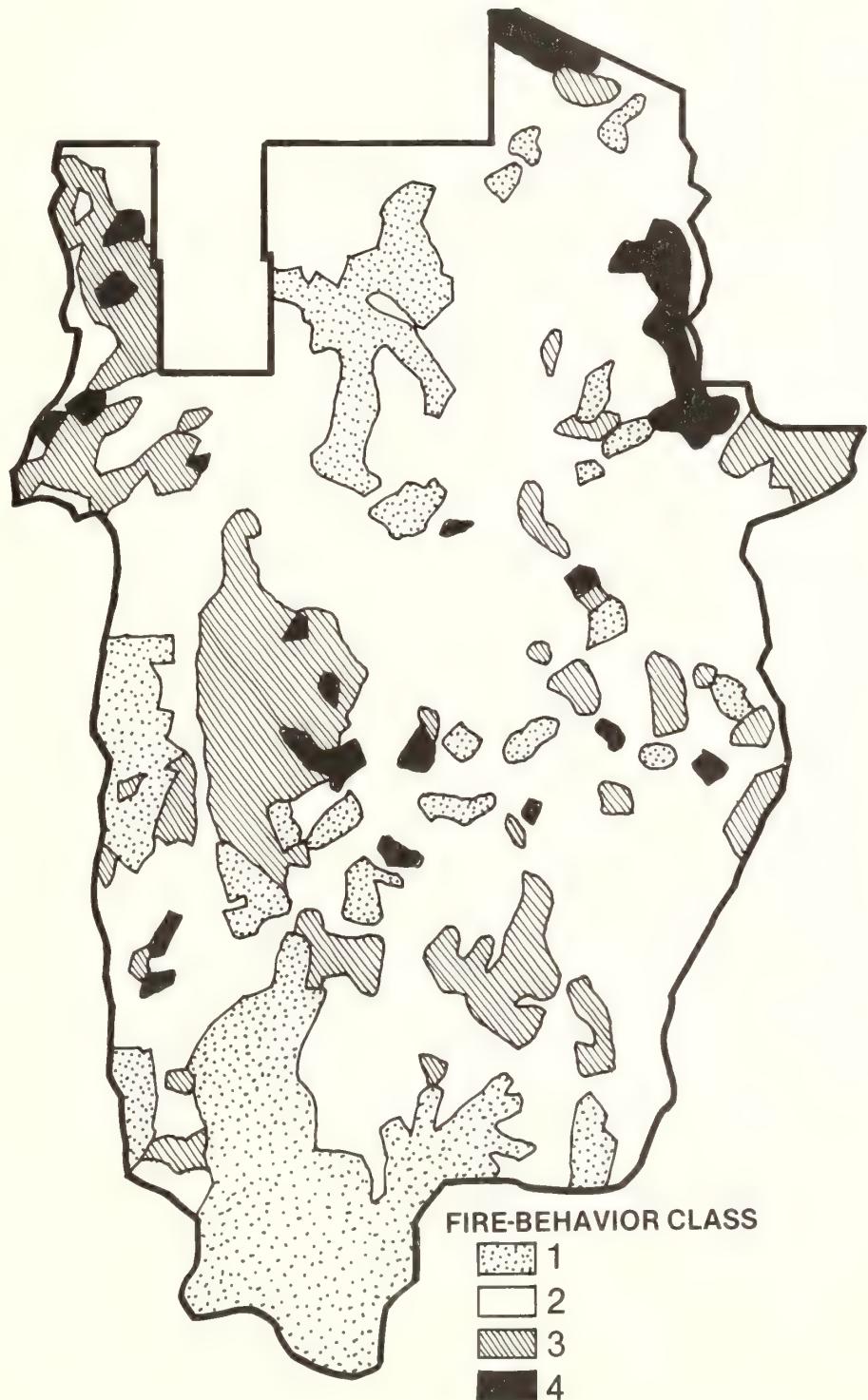


Figure 1.—Cal-Ore Pilot-Test Study fire-behavior map.

Year	Producer price index	Adjusted to 1979
1970	110.4	2.1313
1971	113.9	2.0658
1972	119.1	1.9757
1973	134.7	1.7468
1974	160.1	1.4697
1975	174.9	1.3453
1976	183.0	1.2858
1977	194.2	1.2116
1978	209.3	1.1242
1979	235.3	1.0000

Adjusted to 1979 dollars, cost of damage was \$340 and suppression was \$740 in real dollars.

The average increase was 13 percent per year. If this trend continued through 1980, the cost of doing the job then would be about \$836 per acre. Managers must project costs carefully, however, because trends can change from year to year.

The second step is to identify trends in real values and costs. One way is to ask the question: Was a trend in real suppression costs and real damage values detectable over the period 1970 to 1979? To answer this question, we tested the hypothesis that costs and values, stated in 1979 dollars, were unchanged over time. The test was performed by regressing historical cost on time and then checking for a coefficient on the time variable that was significantly different from zero at the 0.05 level of significance. The following linear regression was used:

$$(\text{corrected cost})_t = b_0 + b_1 (\text{year})$$

where

$$(\text{corrected cost})_t = \text{cost in year } t \text{ in 1979 dollars}$$

(year) = 1970 through 1979

$b_0$  = estimated intercept

$b_1$  = estimated trend

coefficient on the time variable.

We tested the significance of  $b_1$  using the Student's t-test. For suppression costs, the computed t-value was 1.53. The critical t-value for the 0.05 level of significance was 2.262. Because the computed value was less than the critical value, we concluded the evidence is insufficient to reject the hypothesis that  $b_1$  is significantly different from zero. No linear trend occurred in real suppression costs between 1970 and 1979; the damage values and suppression costs were the same throughout the study period. Analysis for damage values showed they, too, remained the same.

Projections of future suppression costs and damage values would be based on the assumption that past trends would continue. The analysis shows we would be justified in using the damage value of \$340 per acre and the suppression cost of \$740 per acre for projecting future damage values and suppression costs.

The economic consequences of fire-management activities can be measured by comparing benefits (damages that are avoided or revenues) and costs. A comparison can be made only if costs and benefits in the future are discounted to the same time. Typically, future real costs (in dollars corrected for inflation) and benefits are discounted to the present. Failure to discount costs and revenues correctly will seriously distort an economic analysis.

The present value of a sequence of suppression costs that will be incurred over the next R years can be written as:

$$PV_{\text{cost}} = C_1/(1+i)^1 + C_2/(1+i)^2 + \dots + C_R/(1+i)^R \quad (1)$$

where

PV = the sum of future real costs discounted to the present

C = annual cost

i = interest rate

R = total years

t = individual years.

Because each of the annual costs (C) is different, we may wish to compute an average annual cost which, when discounted, would have the same present value as PV<sub>cost</sub> in equation (1). If we let r be the equal annual equivalent cost, then:

$$r = [(PV_{\text{cost}})(i)(1+i)^R]/[(1+i)^R - 1]. \quad (2)$$

Note that the equal annual equivalent cost computed with equation (2) is not the simple average of the projected costs. The simple average of projected costs would misstate the true economic consequences of fire management.

A team of USDA Forest Service fire and fuel specialists developed a table (on file, Forest Residues and Energy Program, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon) of value of damage and cost of suppressing wildfire, using costs for their area as a benchmark for a medium site, slope class 2, and access category II (see Glossary for definitions). The land was forested, so figures reflect costs that would result from wildfire on timbered land. Open brushlands or grasslands would naturally have different suppression costs and damage values. Each area would have to be evaluated according to the resources present. The team derived costs above and below using their best judgment and available cost information. Because their figures apply to northwestern Oregon, we adjusted the values to reflect costs for the forests in our study for 1970-79 (table 2). Values are categorized for various sites, slope classes, and accessibilities. The combined values for wildfire costs and resource damage are used for comparing various land capabilities and management options.

**Table 2—Value (per burned acre) of damage and suppression costs for sites, slope classes, and access classes**

Site	Slope class	Damage value	Access class	Suppression costs	Total
<u>Dollars</u>				- - - <u>Dollars</u> - - -	
High	3	714	III	6,512	7,226
			II	4,477	5,191
			I	2,664	3,378
	2	544	III	5,106	5,650
			II	3,071	3,615
			I	1,295	1,839
	1	425	III	3,848	4,273
			II	2,294	2,719
			I	1,036	1,461
<hr/>					
Medium	3	425	III	2,294	2,719
			II	1,295	1,720
			I	1,036	1,461
	2	340	III	1,554	1,894
			II	740	1,080
			I	518	858
	1	289	III	1,036	1,325
			II	629	918
			I	518	807
<hr/>					
Low	3	238	III	1,036	1,274
			II	777	1,015
			I	629	867
	2	153	III	777	930
			II	518	671
			I	370	523
	1	34	III	629	663
			II	370	404
			I	259	293

## Perspective on Land-Management Plans and Cost Tables

Although wildfire statistics must be specific for areas or individual forests, cost and damage tables need not be so localized. For broad land-management planning, only relative costs and values for different management options need be compared—either on a regional, area, or forest basis, whichever reflects costs for the planning area. We used costs for Planning Area V.

## Development of the Protection Cost Table

Protection costs are given for three access classes—(I) roaded, (II) modified, and (III) remote—and four fire-behavior classes (table 3). Access class II and fire-behavior class 2 were used as a base at \$1.75 per acre (1979 dollars). These protection costs were derived from the average cost of protecting the mix of lands in the Region by studying the high and low protection costs, and by estimating the fire-fighting resources and associated costs of protecting a full management unit comprised of one access class and one fire-behavior class.

**Table 3—Protection costs per protected acre per year, Pacific Northwest Region**

Access class	Fire-behavior class			
	1	2	3	4
<u>Dollars</u>				
I	1.00	1.50	2.00	2.50
II	1.25	1.75	2.25	2.50
III	1.50	2.00	2.50	2.50

## Development of the Fuel-Treatment Cost Table

Table 4 was formed by using costs for various fuel treatments, assuming they represent the moderate difficulty presented by slope class 2. Variations from these averages resulted in costs above and below slope class 2.

## Examples of Management Options

**Table 4—Treatment cost per acre (1979 dollars) <sup>1/</sup>**

Treatment <sup>2/</sup>	Slope class	Access class		
		I	II	III
YUM	1	375	600	1,000
	2	350	700	1,200
	3	400	800	1,400
HPB	1	370	400	430
	2	400	430	460
	3	430	460	500
MPB	1	330	--	--
	2	--	--	--
	3	--	--	--
BB	1	200	250	--
	2	250	300	--
	3	300	350	--
UB	1	250	300	350
	2	300	350	400
	3	350	400	450
L&S	1	150	175	250
	2	175	200	275
	3	200	225	300
Crush	1	350	--	--
	2	--	--	--
	3	--	--	--
Air curt	1	1,000	--	--
	2	1,000	--	--
	3	1,100	--	--
Pres fire	1	50	75	150
	2	75	100	200
	3	100	150	250

-- = machines cannot operate in these slope and access classes.

<sup>1/</sup>For visual management I areas, add 50 percent of handpile-and-burn cost to any treatment selected.

<sup>2/</sup>YUM = Yard unmerchantable material

HPB = Hand pile and burn

MPB = Machine pile and burn

BB = Broadcast burn

UB = Underburn

L&S = Lop and scatter

Air curt = Burning with air curtain or similar equipment

Pres fire = Prescribed fire other than BB and UB.

To enable the fire planner to project consequences, information on each management option should include:

- Planned timber rotation or expected vegetation cycle, in years.
- Timber-management prescription planned, what kind and at what point in the rotation (for example, precommercial thinning at 20 years, partial cut at 80 years, and harvest cut at 120 years).
- Access planned by one of three broad classes; roaded, modified, or remote.
- Visual standard expected, such as full retention, partial retention, and so on—as expressed in USDA Forest Service terminology.
- Expectations and constraints on use of prescribed fire—when in the cycle or rotation fire would be used, and what are the recommended intensities (minimum-maximum flame lengths).
- Expected change in public use during the cycle.

Two land-management alternatives formed from actual ones are the basis for the cost-loss examples in the succeeding sections of this report.

### 1. Wilderness management.

- 400-year vegetative cycle.
- No timber removal or culture.
- Trail access only.
- Full retention of natural visual qualities.
- No prescribed fire proposed.
- Public recreation use expected to triple during cycle.

### 2. Timber management.

- 275-year vegetative cycle (rotation).
- Cutting and cultural activity:
  - Precommercial thinning at 20th year.
  - Commercial thinning at 80th year.
  - Commercial thinning at 120th year.
  - Harvest cut at 275th year.
- Conventional road system planned.
- Visual requirement is background.
- Slash treatment by burning—either pile and burn or broadcast burn after each cutting entry.
- Public use expected to double during rotation.

## Projecting Fire-Behavior Ratings for Management Options

To project the fire-behavior rating for each management option through a full cycle of management on each of three slope classes, we evaluated:

- Vegetation progression for broad local land types.
- Time in each stage of progression, fuel conditions, and behavior associated with each stage.
- Effects of cutting, cultural work, and fuel treatment on fire behavior.

Fire-behavior ratings for the wilderness were projected (fig. 2). On the Siskiyou National Forest, this option is generally considered for the high-elevation mixed-conifer type.

Note for slope class 1 on figure 2:

- Fire behavior is expected to be class 3 from year 0 to year 60 during the seedling-sapling stage. Such young stands are usually found growing through the heavy dead-and-down remnants of the preceding stand.
- Fire behavior is expected to be class 2 from year 60 to year 160. During this stage, shading tends to provide a moist microclimate but natural mortality of many pole-sized stems results in a fair amount of dead-and-down fuel.
- Fire behavior is expected to drop to class 1 from year 160 to year 320. This stage is represented by thrifty, full-crowned stands that shade the forest floor. Little residue is contributed from the standing trees. Decay of dead-and-down material is favored.
- Fire behavior is expected to rise to class 2 from year 320 to year 370 because of senescence and death of old-growth trees, which drop from the stand, open the canopy, and add to fuel.
- Fire behavior is expected to rise to class 3 from year 370 to year 400. Old-growth mortality is occurring at an accelerated rate, creating heavy ground fuel and exposure of these fuels to wind and sunlight.

Considering these stages of vegetative progression and projected fire-behavior ratings for slope class 1 areas, we made similar projections for areas in slope classes 2 and 3.

The fire-behavior projection for the timber-management option was made in the same fashion as for the wilderness (fig. 3). On the pilot-test area, this timber option would generally be considered for

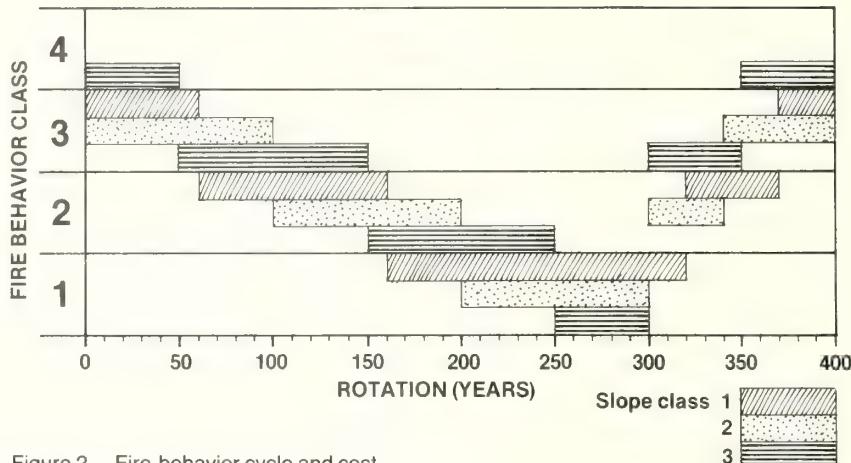


Figure 2.—Fire-behavior cycle and cost projection for wilderness management (low-intensity) option with a 400-year cycle, access class III.

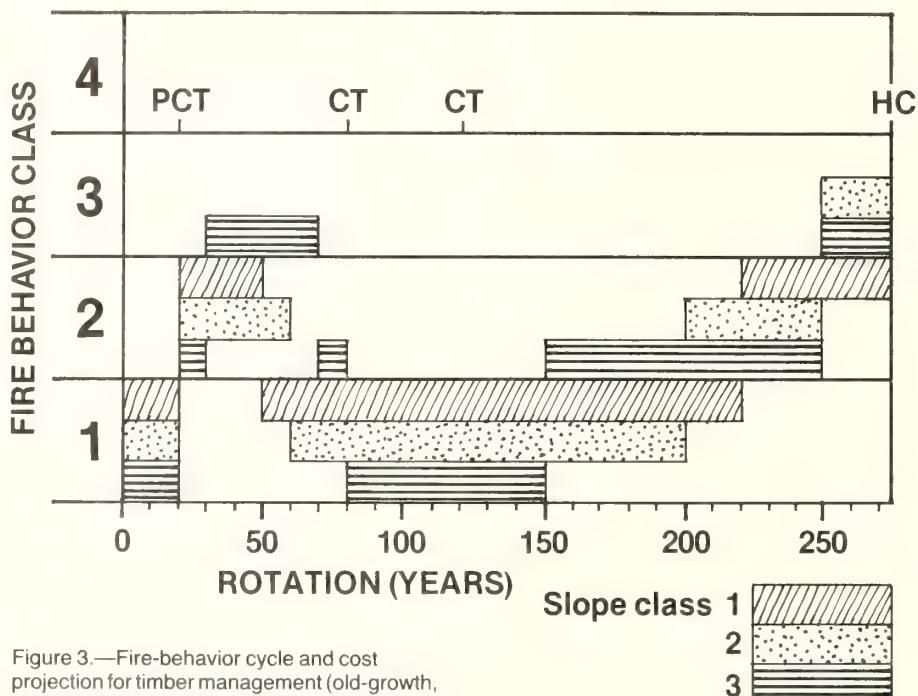


Figure 3.—Fire-behavior cycle and cost projection for timber management (old-growth, high-intensity option) with a 275-year rotation, access class I.

better sites that would support full-crowned stands of ponderosa pine and associated species, or mixed conifer. To project fire behavior for this management option, we note points in the cycle where cutting entries are proposed—precommercial thinning (PCT), commercial thinning (CT), and harvest cut (HC). We also assumed that an appropriate residue treatment would be performed after each of these cutting entries.

Planners using this procedure for projecting fire behavior through a cycle of management will find photo series publications on the activity and natural residue levels, and companion fire-behavior tables, valuable (Blonski and Schramel 1981; Fischer 1981a, 1981b, 1981c; Koski and Fischer 1979; Maxwell and Ward 1976a, 1976b, 1979, 1980; Sandberg and Ward 1981; Ward and Sandberg 1981a, 1981b).

## Projecting Costs for Protection and Fuel Treatment

Calculations of costs for fire protection and fuel treatment were made (tables 5 and 6). Note that graph projections in slope class 1 show fire behavior through the cycle is expected to be at class 3 for 90 years, at class 2 for 150 years, and at class 1 for 160 years.

Applying protection costs from table 3, and using the present value and equal annual payment formulas at 6-percent interest, the costs were:

90 years at \$2.50 per year;  
150 years at \$2.00 per year; and  
160 years at \$1.50 per year.

Discounting these values to the present gives:

$$\begin{aligned} PV_1 &= (2.50/.06) [(1.06^{90}-1)/1.06^{90}] \\ &= \$41.45. \\ PV_2 &= [2.00/((.06)1.06^{90})] [(1.06^{150}-1) \\ &\quad /1.06^{150}] = \$0.18. \\ PV_3 &= [1.50/((.06)1.06^{240})] [(1.06^{160}-1) \\ &\quad /1.06^{160}] = \$0.00002. \\ PV_1 + PV_2 + PV_3 &= \$41.63. \end{aligned}$$

The equal annual payment calculation is:

$$\begin{aligned} r &= [(41.63)(.06)]/[(1.06^{400})/(1.06^{400}-1)] \\ &= \$2.50 \text{ per acre per year.} \end{aligned}$$

The same calculations were made for slope classes 2 and 3 (table 5). No calculations were made for fuel treatment because the management option did not propose any prescribed burning or other fuel work.

Fire-behavior classes for the timber-management (high intensity) option, based on graph projections (fig. 3), show—for slope class 1—that fire behavior will not reach class 3 during the rotation, will be at class 2 for 85 years, and at class 1 for 190 years. Applying costs from table 4 gave:

0 years at \$2.00 per year;  
85 years at \$1.50 per year; and  
190 years at \$1.00 per year.

Discounted to the present, the values are:

$$\begin{aligned} PV_1 &= 0. \\ PV_2 &= (1.50/.06) [(1.06^{85}-1)/1.06^{85}] \\ &= \$24.82. \\ PV_3 &= [1.00/((.06)1.06^{85})] [(1.06^{190}-1) \\ &\quad /1.06^{190}] = \$0.12. \\ PV_1 + PV_2 + PV_3 &= \$24.94. \end{aligned}$$

The equal annual payment for this option was:

$$\begin{aligned} r &= [24.94(.06)]/[(1.06^{275})/(1.06^{275}-1)] \\ &= \$1.50. \end{aligned}$$

Similar calculations were made for slope classes 2 and 3.

This management option called for fuel treatment after each entry.

**Table 5—Protection costs (1979 dollars) and projected percent of cycle  $\geq$  fire-behavior class 3 for wilderness management cycle shown in figure 2**

Fire-behavior class	Slope class	Time	Cost per acre per year (from table 3)	Cost per acre per year for all fire-behavior classes	Time in fire-behavior class $\geq$ 3	Portion of cycle
		Years	----- Dollars -----		Years	Percent
3		90	2.50			
2	1	150	2.00	2.50 <sup>1/</sup>	90	22.5
1		160	1.50			
3		160	2.50			
2	2	140	2.00	2.50	160	40.0
1		100	1.50			
4		100	2.50			
3		150	2.50			
2	3	100	2.00	2.50	250	62.5
1		50	1.50			

<sup>1/</sup> Remember, these are the equal annual payment costs after being discounted to the present.

**Table 6—Protection and treatment costs (1979 dollars) and projected percent of cycle  $\geq$  fire-behavior class 3 for timber-management cycle shown in figure 5**

Fire-behavior class	Slope class	Time	Protection costs (per acre)			Silvicultural treatment	Residue treatment	Treatment costs (per acre)		Time in fire-behavior class $\geq$ 3	Portion of cycle
			Cost per year (from table 3)	Cost per year for all fire-behavior classes				Cost	Cost per year		
			Years	Dollars				Dollars	Years	Percent	
3	1	0	2.00			PCT	HPB	370			
2		85	1.50	1.50 <sup>1/</sup>		CT	MPB	660	7.13	0	0
1		190	1.00			H	BB	200			
3	2	25	2.00			PCT	HPB	400			
2		90	1.50	1.88		CT	HPB	800	7.73	25	9.1
1		160	1.00			H	BB	250			
3	3	65	2.00			PCT	HPB	430			
2		120	1.50	1.99		CT	HPB	960	8.34	65	23.6
1		90	1.00			H	BB	300			

<sup>1/</sup> These are the equal annual payment costs after being discounted to the present.

Entries proposed are one precommercial thinning (PCT), two commercial thinnings (CT), and a harvest cut (HC). Based on cost, desirability, and practicality, a method of treatment to follow each entry was identified. These were, for slope class 1:

- After PCT, hand pile and burn.
- After CT, machine pile and burn.
- After the final harvest, broadcast burn.

Calculations for this treatment work, using costs from table 3, is:

PCT at \$370 per acre;  
CT at \$660 per acre (\$330 for two CT);  
and HC at \$200 per acre.

Discounting these values to the present would give:

$$\begin{aligned} PV &= 370/(1.06)^{20} + 330/(1.06)^{80} \\ &\quad + 330/(1.06)^{120} + 200/(1.06)^{275} \\ &= \$118.79. \end{aligned}$$

The equal annual payment would be \$7.13.

Similar calculations were made for slope classes 2 and 3 (table 6).

## Projecting Wildfire Costs and Losses

The form "Fire in Land Management Planning" (fig. 4) was designed to aid in calculating projected costs and losses from wildfire for a management option practiced on three site categories within each of the three slope classes.

### Wilderness Management Option

Figure 5 shows the completed calculation of cost and loss for the wilderness option. The fire-behavior classes of fuels in all of area V were believed to be the same proportions as those in the pilot-test area. Table 1 shows that 17 percent of the planning area currently is in critical fire-behavior classes 3 and 4. Sample information was recorded at the top of the form. Next, the percentages of acres lost per year listed by cause of fire (table 1) were transferred to the form on lines 1, 2, and 3: lightning, 0.00176 percent; industrial, 0.00931 percent; and public use, 0.00581 percent. Changes in risk of fire starts related to management option and expected future use (cutting and noncommercial use) were reviewed to determine risk factors. Because risk from lightning is unchanged by either management option or expected use, no factor column is provided on the form. No industrial entries were permitted by this management option, so the risk factor in line 4 was zero and the adjusted loss from industrial causes, line 6, became zero. Expected public use was expected to triple, so a factor of 3 in line 5 was used to adjust the 0.00931 in line 3 to 0.01743 in line 7. Expected losses from risk were then summed to 0.01919 percent on line 8, the adjusted percent burned per year because of changes in risk.

Change in expected loss to wildfire, from potential change in fire behavior brought about by the management option, was determined by first analyzing table 5. This revealed that during the cycle, fuels in slope class 1 would be in fire-behavior classes 3 and 4 for 22.5 percent of the time, slope class 2 in behavior classes 3 and 4 for 40 percent of the time, and slope class 3 in behavior classes 3 and 4 for 62.5 percent of the time. These results were entered in lines 9, 10, and 11.

Most acres lost to wildfire were in fire-behavior classes 3 and 4. Because 17 percent of area V was in fire-behavior classes 3 and 4, this percent was divided into the percentages of 22.5, 40.0, and 62.5 to arrive at the fire-behavior factors of 1.3235, 2.3529, and 3.6765, shown in lines 12, 13, and 14.

The adjusted acreage burned (risk percentage) from line 8 was then further adjusted by the fire-behavior factors from lines 12, 13, and 14, to produce the expected percentage of loss from wildfire for the three slope classes (lines 15, 16, and 17).

Appropriate cost-loss values from table 2 were entered in column 21. Note that this example area is in access class III (remote), and three site categories within each slope class are considered. Lines 15, 16, and 17 percentages were divided by 100 and then multiplied by the cost-loss value in column 21 to produce the column 22 cost-loss figures, which are dollars of cost-loss per acre managed under this management option, depending on slope class and site category.

Column 23 displays, by three slope classes, the expected percentage of loss to wildfire during a full cycle for lands managed under this option. This projection was made by multiplying the annual loss estimate (column 18) by the years in the planned cycle.

### Timber Management Option

Figure 6 shows the completed calculation for this management option. As with the previous example, annual percentages of wildfire loss by broad causes were entered in lines 1, 2, and 3. This option calls for four cultural or cutting entries in the stand during the cycle. A risk factor of four was therefore used in line 4. Noncommercial use under this option is expected to double in the next cycle, so a factor of two was used in line 5. The projection, because of risk given in line 8, is 0.05062 percent. Fire-behavior percentages were obtained from table 6. The balance of the calculations for this example followed the same procedure as used for the previous example.

Planning option \_\_\_\_\_ Planning unit \_\_\_\_\_  
 Specific practice \_\_\_\_\_  
 Accessibility class \_\_\_\_\_ Percent area in fire behavior (FB)  $\geq$  class 3 \_\_\_\_\_  
 Visual management code \_\_\_\_\_ Rotation (years) \_\_\_\_\_  
 Fire management \_\_\_\_\_  
 Projected use \_\_\_\_\_

#### RISK CALCULATION

Percent area burned from:

Lightning	1. _____	Risk factor: Industrial use 4. _____
Industrial use	2. _____	General public use 5. _____
General public use	3. _____	

Adjusted area burned:

6. \_\_\_\_\_ (2 x 4)    7. \_\_\_\_\_ (3 x 5)    8. \_\_\_\_\_ (1 + 6 + 7)

#### FIRE-BEHAVIOR CALCULATION

Slope class

Projected percent of cycle $\geq$ fire-behavior class 3	1. _____	2. _____
	9. _____	10. _____
		11. _____

Fire-behavior factor	12. _____	13. _____
	(9 $\div$ FB)	(10 $\div$ FB)
		14. _____
		(11 $\div$ FB)

Expected loss per year	15. _____	16. _____
	(8 x 12)	(8 x 13)
		17. _____
		(8 x 14)

#### COST-LOSS CALCULATION

18. Expected loss per year	19. Slope class	20. Site	21. Cost-loss value per acre (from table 2)	22. Cost-loss coefficient $\left(\frac{18 \times 21}{100}\right)$	23. Projected percent loss per cycle (18 x years) in cycle
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High \_\_\_\_\_

15. \_\_\_\_\_ 1 Med. \_\_\_\_\_ \_\_\_\_\_

Low \_\_\_\_\_

High \_\_\_\_\_

16. \_\_\_\_\_ 2 Med. \_\_\_\_\_ \_\_\_\_\_

Low \_\_\_\_\_

High \_\_\_\_\_

17. \_\_\_\_\_ 3 Med. \_\_\_\_\_ \_\_\_\_\_

Low \_\_\_\_\_

Figure 4.—Form for evaluating fire in land-management planning.

Planning option WILDERNESS Planning unit ILLINOIS VALLEY  
 Specific practice WILDERNESS  
 Accessibility class III Percent area in fire behavior (FB)  $\geq$  class 3 17  
 Visual management code PRESERVATION Rotation (years) 400  
 Fire management SUPPRESS ALL FIRES AND NO PRESCRIBED BURNING  
 Projected use PUBLIC USE EXPECTED TO TRIPLE  
RISK CALCULATION

Percent area burned from:

Lightning	1. <u>0.00176</u>	Risk factor: Industrial use 4. <u>0</u>
Industrial use	2. <u>0.00931</u>	General public use 5. <u>3</u>
General public use	3. <u>0.00581</u>	

Adjusted area burned:

6. 0 (2 x 4) 7. 0.01743 (3 x 5) 8. 0.01919 (1 + 6 + 7)

FIRE-BEHAVIOR CALCULATION

Slope class

Projected percent of cycle $\geq$ fire-behavior class 3	1	2	3
9. <u>22.5</u>	10. <u>40.0</u>	11. <u>62.5</u>	

Fire-behavior factor	12. <u>1.3235</u> $(9 \div FB)$	13. <u>2.3529</u> $(10 \div FB)$	14. <u>3.6765</u> $(11 \div FB)$
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Expected loss per year	15. <u>0.02540</u> $(8 \times 12)$	16. <u>0.04515</u> $(8 \times 13)$	17. <u>0.07055</u> $(8 \times 14)$
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COST-LOSS CALCULATION

18. Expected loss per year	19. Slope class	20. Site	21. Cost-loss value per acre (from table 2)	22. Cost-loss coefficient per acre $(\frac{18 \times 21}{100})$	23. Projected percent loss per cycle per year ( $18 \times$ years) in cycle
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		High	<u>4,273</u>	<u>1.09</u>	
15. <u>0.0254</u>	1	Med.	<u>1,325</u>	<u>0.34</u>	<u>10.2</u>
		Low	<u>663</u>	<u>0.17</u>	
		High	<u>5,650</u>	<u>2.55</u>	
16. <u>0.0452</u>	2	Med.	<u>1,894</u>	<u>0.86</u>	<u>18.1</u>
		Low	<u>930</u>	<u>0.42</u>	
		High	<u>7,226</u>	<u>5.10</u>	
17. <u>0.0706</u>	3	Med.	<u>2,719</u>	<u>1.92</u>	<u>28.2</u>
		Low	<u>1,274</u>	<u>0.90</u>	

Figure 5.—Sample form showing wilderness planning option.

Planning option TIMBER MANAGEMENT Planning unit ILLINOIS VALLEY  
 Specific practice TIMBER HARVEST  
 Accessibility class I Percent area in fire behavior (FB)  $\geq$  class 3 17  
 Visual management code BACKGROUND Rotation (years) 275  
 Fire management TREAT RESIDUE AFTER EACH ENTRY  
 Projected use WOODCUTTING, CAMPING, HUNTING TO DOUBLE  
RISK CALCULATION

Percent area burned from:

Lightning	1. <u>0.00176</u>	Risk factor: Industrial use 4. <u>4</u>
Industrial use	2. <u>0.00931</u>	General public use 5. <u>2</u>
General public use	3. <u>0.00581</u>	

Adjusted area burned:

6. 0.03724 (2 x 4) 7. 0.01162 (3 x 5) 8. 0.05062 (1 + 6 + 7)

FIRE-BEHAVIOR CALCULATION

Slope class

Projected percent of cycle $\geq$ fire-behavior class 3	1	2	3
9. <u>0</u>	10. <u>9.1</u>	11. <u>23.6</u>	

Fire-behavior factor	12. <u>0</u> (9 $\div$ FB)	13. <u>0.5353</u> (10 $\div$ FB)	14. <u>1.3882</u> (11 $\div$ FB)
----------------------	----------------------------	----------------------------------	----------------------------------

Expected loss per year	15. <u>0</u> (8 x 12)	16. <u>0.02710</u> (8 x 13)	17. <u>0.07027</u> (8 x 14)
------------------------	-----------------------	-----------------------------	-----------------------------

COST-LOSS CALCULATION

18.	19.	20.	21.	22.	23.
Expected loss per year	Slope class	Site	Cost-loss value per acre (from table 2)	Cost-loss coefficient per acre ( $\frac{18 \times 21}{100}$ )	Projected percent loss per cycle (18 x years) in cycle

		High	<u>1,461</u>	<u>0</u>	
15. <u>0</u>	1	Med.	<u>807</u>	<u>0</u>	<u>0</u>
		Low	<u>293</u>	<u>0</u>	
		High	<u>1,839</u>	<u>0.50</u>	
16. <u>0.02710</u>	2	Med.	<u>858</u>	<u>0.23</u>	<u>7.5</u>
		Low	<u>523</u>	<u>0.14</u>	
		High	<u>3,378</u>	<u>2.37</u>	
17. <u>0.07027</u>	3	Med.	<u>1,461</u>	<u>1.03</u>	<u>19.3</u>
		Low	<u>867</u>	<u>0.61</u>	

Figure 6.—Sample form showing timber-management planning option.

## Assembly of Cost-Loss Projections

Example 1 in figure 7 assembles, for the wilderness management option, projections of protection and fuel treatment from tables 5 and 6, suppression and damage values, and percent lost to wildfire per cycle from figure 5. These are shown separately, for convenience.

Example 2 in figure 7 assembles like projections for the timber option.

Example 1--Wilderness		Example 2--Timber harvest	
<b>Protection</b>		<b>Protection</b>	
Slope class 1 = \$2.50		Slope class 1 = \$1.50	
Slope class 2 = \$2.50		Slope class 2 = \$1.88	
Slope class 3 = \$2.50		Slope class 3 = \$1.99	
<b>Fuel treatment -- None</b>		<b>Fuel treatment</b>	
Suppression and damage (per planned acre per year)		Suppression and damage (per planned acre per year)	
High \$1.09		High \$0.00	
Slope class 1	site Medium \$0.34	Slope class 1	site Medium \$0.00
	Low \$0.17		Low \$0.00
	High \$2.55		High \$0.50
Slope class 2	site Medium \$0.86	Slope class 2	site Medium \$0.23
	Low \$0.42		Low \$0.14
	High \$5.10		High \$2.37
Slope class 3	site Medium \$1.92	Slope class 3	site Medium \$1.03
	Low \$0.90		Low \$0.61
<b>Percent of area lost to wildfire per cycle</b>		<b>Percent of area lost to wildfire per cycle</b>	
Slope class 1 = 10.2%		Slope class 1 = 0.0%	
Slope class 2 = 18.1%		Slope class 2 = 7.5%	
Slope class 3 = 28.2%		Slope class 3 = 19.3%	

Figure 7.—Summary of cost-loss for two management options.

## Study Assumptions

## Metric Conversion

Statistics on Causes of Wildfire and Area Burned	Risk Projections	Multiply	by	To obtain
We believe statistics on causes of wildfire and area burned should be taken from the current decade if they are to reflect current risks and effectiveness of suppression. Such statistics for a small area, however, do not provide a sound base because fire occurs sporadically and behaves erratically. We therefore used wildfire statistics for the whole USDA Forest Service Region 6 planning area.	Expected increases in industrial entries and public use vary with management options. We believe that current fire-prevention programs are relatively sophisticated and, although they would expand to meet increasing risks, they would not necessarily be more effective. A directly proportionate risk factor for expected increase was therefore used in the study examples.	Acres Feet Chains	0.4047 0.3048 20.1168	hectares meters meters
Use of area wildfire statistics required estimating amounts of fuels critical to fire-behavior (classes greater than or equal to 3). We used a fire-behavior map for the pilot-test area to make a comparative estimate of critical fuels in the area.	Users of the procedure may wish to change factors for risk based on their own insights. They may decide, for example, that a management option that anticipates a doubling of public use would likely result in a risk factor of 1.5 rather than 2.0, indicating a commensurate increase in effective measures for fire prevention is on the horizon.			
The area V statistics on wildfire and the proportion of fuels in the critical category were used to make the projections on loss from changes in fuel conditions and fire-behavior classes attributable to management.				
Users of this procedure will want to be assured that the percentage of fuels falling in the critical fire-behavior class is derived from the same area as the wildfire statistics.				
Wildfire and Critical Fuels				
Critical fuels in the study were considered to be those in fire-behavior classes 3 and 4, as rated in Part 2 of this study. These are fuels with an expected spread rate greater than or equal to 8.5 chains per hour or flame lengths greater than or equal to 7.5 feet.				
We believe fires in lower behavior classes can generally be controlled when small and that fires escaping control and consuming large areas generally do so where critical fuels are present. Projections of wildfire loss related to management option are therefore based on critical fuels produced by the management option over time.				

## Literature Cited

- Blonski, Kenneth S.; John L. Schramel.** Photo series for quantifying natural forest residues: southern cascades, northern sierra Nevada. Gen. Tech. Rep. PSW-56. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; **1981**. 145 p.
- Egging, Louis T.; Barney, Richard J.; Thompson, Rita P.** A conceptual framework for integrating fire considerations in wildland planning. Res. Note INT-278. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; **1980**. 11 p.
- Fischer, William C.** Photo guide for appraising downed woody fuels in Montana forests: grand fir—larch—Douglas-fir, western hemlock, western hemlock—western redcedar, and western redcedar cover types. Gen. Tech. Rep. INT-96. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; **1981a**. 53 p.
- Fischer, William C.** Photo guide for appraising downed woody fuels in Montana forests: interior ponderosa pine, ponderosa pine—larch—Douglas-fir, larch—Douglas-fir, and interior Douglas-fir cover types. Gen. Tech. Rep. INT-97. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; **1981b**. 133 p.
- Fischer, William C.** Photo guide for appraising downed woody fuels in Montana forests: lodgepole pine, and Engelmann spruce—subalpine fir cover types. Gen. Tech. Rep. INT-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 141 p.
- Koski, Wayne H.; Fischer, William C.** Photo series for appraising thinning slash in north Idaho, western hemlock, grand fir, and western redcedar timber types. Gen. Tech. Rep. INT-46. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; **1979**. 49 p.
- Maxwell, Wayne G.; Ward, Franklin R.** Photo series for quantifying forest residues in the : coastal Douglas-fir—hemlock type, coastal Douglas-fir—hardwood type. Gen. Tech. Rep. PNW-51. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1976a**. 103 p.
- Maxwell, Wayne G.; Ward, Franklin R.** Photo series for quantifying forest residues in : ponderosa pine type, ponderosa pine and associated species type, and lodgepole pine type. Gen. Tech. Rep. PNW-52. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1976b**. 73 p.
- Maxwell, Wayne G.; Ward, Franklin R.** Photo series for quantifying forest residues in the: sierra mixed conifer type, sierra true fir type. Gen. Tech. Rep. PNW-95. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1979**. 79 p.
- Maxwell, Wayne G.; Ward, Franklin R.** Photo series for quantifying natural forest residues in common vegetation types of the Pacific Northwest. Gen. Tech. Rep. PNW-105. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1980**. 229 p.
- Maxwell, Wayne G.; Ward, Franklin R.** Fuels and fire in land-management planning: Part 1. Forest-fuel classification. Gen. Tech. Rep. PNW-131. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1981**. 12 p.
- Sandberg, David V.; Ward, Franklin R.** Predictions of fire behavior and resistance to control for use with photo series for the Douglas-fir—hemlock type and the coastal Douglas-fir—hardwood type. Gen. Tech. Rep. PNW-116. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1981**. 60 p.
- Ward, Franklin R.; Sandberg, David V.** Predictions of fire behavior and resistance to control for use with photo series for the sierra mixed conifer type and the sierra true fir type. Gen. Tech. Rep. PNW-114. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1981a**. 48 p.
- Ward, Franklin R.; Sandberg, David V.** Predictions of fire behavior and resistance to control for use with photo series for the ponderosa pine type, ponderosa pine and associated species type, and lodgepole pine type. Gen. Tech. Rep. PNW-115. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1981b**. 46 p.

# Glossary

## Access Classes

Roaded areas (class I) would have a conventional road system. A modified area (class II) would require logging by long skylines, balloon, or helicopter, or would, for management reasons, have a restricted conventional road system and require short hiking distances for forest users and managers. A remote area (class III) would require long hiking distances, such as in a wilderness.

## Fire-Behavior Classes

Fire-behavior class	Rate of spread <i>Feet/minute</i>	Flame length <i>Feet</i>
1	0-2.4	0-3.4
2	2.5-8.4	3.5-7.4
3	8.5-29.4	7.5-11.4
4	29.5 +	11.5 +

The higher of the two fire-behavior factors determines the fire-behavior class rating.

## Site Classes

Low – thin, rocky soils generally found on ridgetops or steep slopes. Restocking is not adequate, and the potential for timber yield is low.

Medium – more productive soils than low class, with soils depths 1 to 2 feet. Generally found on gentle slopes with adequate restocking and good potential for timber yield.

High – deep, fertile soils generally found on valley or canyon bottoms. Restocking potential is excellent with a high annual timber yield.

Note: These definitions are purposely stated in general terms. The land manager may need to redefine these site categories to reflect local conditions.

## Slope Classes

Slope class	Percent slope
1	0 - 30
2	31 - 60
3	61 +

**Maxwell, Wayne G.; Sandberg, David V.; Ward, Franklin R.** Fuels and fire in land-management planning: Part 3. Costs and losses for management options. Gen. Tech. Rep. PNW-158. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983**. 18 p.

An approach is illustrated for computing expected costs of fire protection; fuel treatment; fire suppression; damage values; and percent of area lost to wildfire for a management or rotation cycle. Input is derived from Part 1, a method for collecting and classifying the total fuel complex, and Part 2, a method for appraising and rating probable fire behavior. This approach can be used locally for fire management and in land-management planning.

Keywords: Fire management, fuels (forest fire), fire behavior (forest), fire planning, management planning (forest).

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Portland, Oregon 97208

1983

# WILDLIFE HABITATS IN MANAGED RANGELANDS-- THE GREAT BASIN OF SOUTHEASTERN OREGON **BIGHORN SHEEP**



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FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

## **Abstract**

Habitat in southeastern Oregon that was used by California bighorn sheep until about 1916 can be managed to maintain herds that have been reintroduced into the area and to accommodate additional herds. Survival and productivity are enhanced by management based on an understanding of the animal's needs. These include appropriate interspersion of adequate water, forage, and escape terrain, lack of competition with other grazing ungulates for food and water, and absence of disturbance.

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This publication is part of the series **Wildlife Habitats in Managed Rangelands—The Great Basin of Southeastern Oregon**. The purpose of the series is to provide a range manager with the necessary information on wildlife and its relationship to habitat conditions in managed rangelands in order that the manager may make fully informed decisions.

The information in this series is specific to the Great Basin of southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands. The purpose of the series is to provide specific information for a particular area but in doing so to develop a process for considering the welfare of wildlife when range management decisions are made.

The series is composed of 14 separate publications designed to form a comprehensive

whole. Although each part will be an independent treatment of a specific subject, when combined in sequence, the individual parts will be as chapters in a book.

Individual parts will be printed as they become available. In this way the information will be more quickly available to potential users. This means, however, that the sequence of printing will not be in the same order as the final organization of the separates into a comprehensive whole.

A list of the publications in the series, their current availability, and their final organization is shown on the inside back cover of this publication.

**Wildlife Habitats in Managed Rangelands—The Great Basin of Southeastern Oregon** is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and United States Department of the Interior, Bureau of Land Management.



## Introduction

Bighorn sheep<sup>1</sup> were once abundant throughout Western North America. Since 1900, however, they have declined in most areas (fig. 1) and many populations have been eliminated (Buechner 1960, Wagner 1978). Population declines have been attributed to hunting, to parasites and disease, and to competition with domestic livestock for forage, and with humans for space (Buechner 1960, Davis and Taylor 1939, Honess 1942, Honess and Frost 1942, Packard 1946). Wildlife agencies in the western regions of Canada, the United States, and Mexico have initiated programs to maintain or enhance existing populations of bighorn sheep and to reintroduce them into historic ranges (Spalding and Mitchell 1970, Trefethen 1975). But, unless there is better land management, a decline of 8 percent can be expected in the next 25 years on land managed by the Bureau of Land Management (BLM), U.S. Department of the Interior (Jahn and Trefethen 1978).

In the Great Basin the situation is somewhat different. Although some transplant attempts have failed (Trefethen 1975), the States have been successful in reintroducing bighorn sheep into some historic ranges (Trefethen 1975, Yoakum 1973).

Three subspecies of bighorn sheep were endemic to the Great Basin in the past: Rocky Mountain, California, and desert bighorns (Bailey 1936, Buechner 1960, Cowen 1940, Hall and Kelson 1959, Seton 1929). The California bighorn sheep, indigenous to the southeastern Oregon portion of the Great Basin, disappeared around 1916 (Bailey 1936). As a result of transplants, the area again has several populations of California bighorn sheep (Trefethen 1975). If these once-native sheep are to remain, it is essential to maintain or enhance habitats that meet their biological requirements.

Bighorn sheep have evolved unique social and behavioral traits. They occupy traditional ranges and are slow to pioneer new habitats (Geist 1971). This means that careful manage-

<sup>1</sup> Scientific and common names and their sources are listed in the appendix.

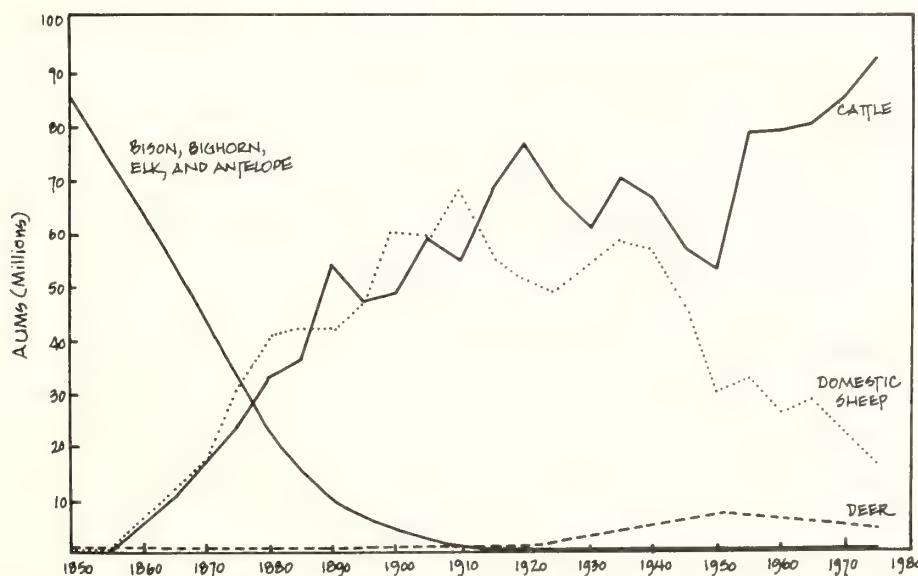


Figure 1.—Grazing of wild ungulates has declined in the western United States since 1850 while grazing of domestic ungulates has increased (redrawn from Wagner 1978:137).

ment of the habitat of existing herds is critical. Much habitat used by herds in the past is publicly administered and is suitable for additional transplant attempts (Yoakum 1971, 1973). Some publicly administered habitat, however, is now unsuitable because of past abuse (McCutchen 1981). Management techniques are available to make these areas again suitable for bighorn sheep, and interim management should not preclude opportunities to reestablish herds in the future.

Our purpose is to help land and wildlife managers evaluate, maintain, and enhance habitat for bighorn sheep by providing information that will enable them to: (1) recognize potential habitat on the basis of geomorphic features and plant communities; (2) predict the consequences of management actions; and (3) select appropriate management alternatives.

Information in this chapter was developed specifically for California bighorn sheep habitat in the Great Basin of southeastern Oregon. Few scientific studies of bighorn sheep habitat and management have been made in that part of the Great Basin. Consequently, we have used some information from other areas of the Great Basin or from other regions. Because such studies have frequently dealt with the desert or Rocky Mountain subspecies, the information presented here should have application to all bighorn sheep, with appropriate local adjustments.

We have made the following assumptions:

1. Extensive areas of historic habitat, presently unoccupied by bighorn sheep, can support herds or can be made capable of supporting herds.
2. Land uses can be tailored to provide areas of sufficient size to maintain viable populations.
3. Where there are conflicts between bighorn sheep and other ungulates for forage, water, or cover on public land, it may be necessary to give priority to bighorn sheep.
4. The information presented here is concerned with maintaining natural populations of free-ranging wild sheep; we are not addressing situations where populations can be maintained only by artificial means.

## Characteristics of Habitat

Bighorn sheep generally inhabit remote, steep, rugged terrain, such as mountains, canyons, and escarpments where precipitation is low and evaporation is high (fig. 2). Plant communities are usually low and open in structure and stable, at or near climax. Sagebrush/grassland steppes and cold desert shrublands are the dominant types.

Bighorn sheep ranges in southeastern Oregon include several plant communities (Dealy et al. 1981) that reflect variations in elevation, slope, aspect, soil type, and precipitation (fig. 3). Summer ranges vary from subalpine meadows or grasslands at elevations above 2 287 meters (7,500 ft), to sagebrush/grasslands or shrublands that are dominant at elevations above 1 220 meters (4,000 ft). Winter ranges are usually below 1 830 meters (6,000 ft) and are characterized by shrub/grasslands or shrublands. Communities dominated by trees or tall shrubs such as aspen, cottonwood, fir, pine, juniper, mountain mahogany, squaw apple, and cherry, may occur throughout both summer and winter ranges, but there are no large densely forested areas.

Some bighorn sheep herds are year-long residents on a given area, with little or no spatial separation of summer and winter ranges (Blood 1963a, Drewek 1970, Demarchi and Mitchell 1973, Haas 1979, Kornet 1978, Van Dyke 1978). Other herds migrate several miles between summer and winter ranges and occupy areas that include a variety of elevations and environmental conditions (Blood 1963a, Geist 1971, Shannon et al. 1975). Both summer and winter ranges must provide freedom from disturbance and a proper juxtaposition of forage, escape terrain, and water if viable populations are to be maintained.

The major needs of bighorn sheep are: forage, water, thermal protection, and areas for escape, rutting, and lambing. If forage, water, and escape terrain are available, varying amounts of thermal protection will also be provided and rutting and lambing will normally occur. There are, however, cases where bighorn sheep move to particular areas to rut or lamb (Geist 1971, Kornet 1978). Management should not interfere with this movement.

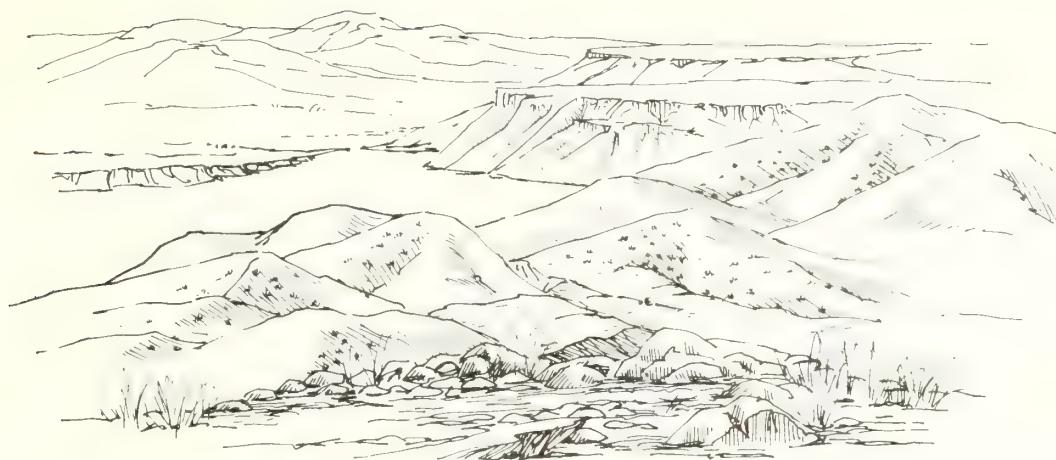


Figure 2.—Mountains, canyons, and escarpments provide bighorn sheep habitat.



Figure 3.—An example of bighorn sheep habitat in southeastern Oregon (photo by Walt Van Dyke).

## ESCAPE AREAS

Cliffs, rock rims, rock outcroppings, and bluffs typify escape habitat, which is primarily used for bedding (Davis and Taylor 1939, Hailey 1971, Hansen 1980, Kornet 1978, Van Dyke 1978) and for escape from perceived danger (Frisina 1974, Geist 1971, Hansen 1980, Leslie and Douglas 1979, Woolf 1968). Steep broken cliffs with traversable terraces are desirable; sheer, vertical cliffs are not (fig. 4). Where cliffs are lacking, steep slopes are used for escape

(Demarchi and Mitchell 1973). Unstable geomorphic features such as talus are also used for escape and bedding.

We have no specific data on sizes of cliffs suitable for bedding and escape areas. We have estimated minimum size requirements on the basis of criteria provided by Maser et al. (1979). The importance of cliffs varies with size (fig. 5). For example, cliffs that provide thermal cover, bed-sites, and escape terrain may not be large enough for lambing.

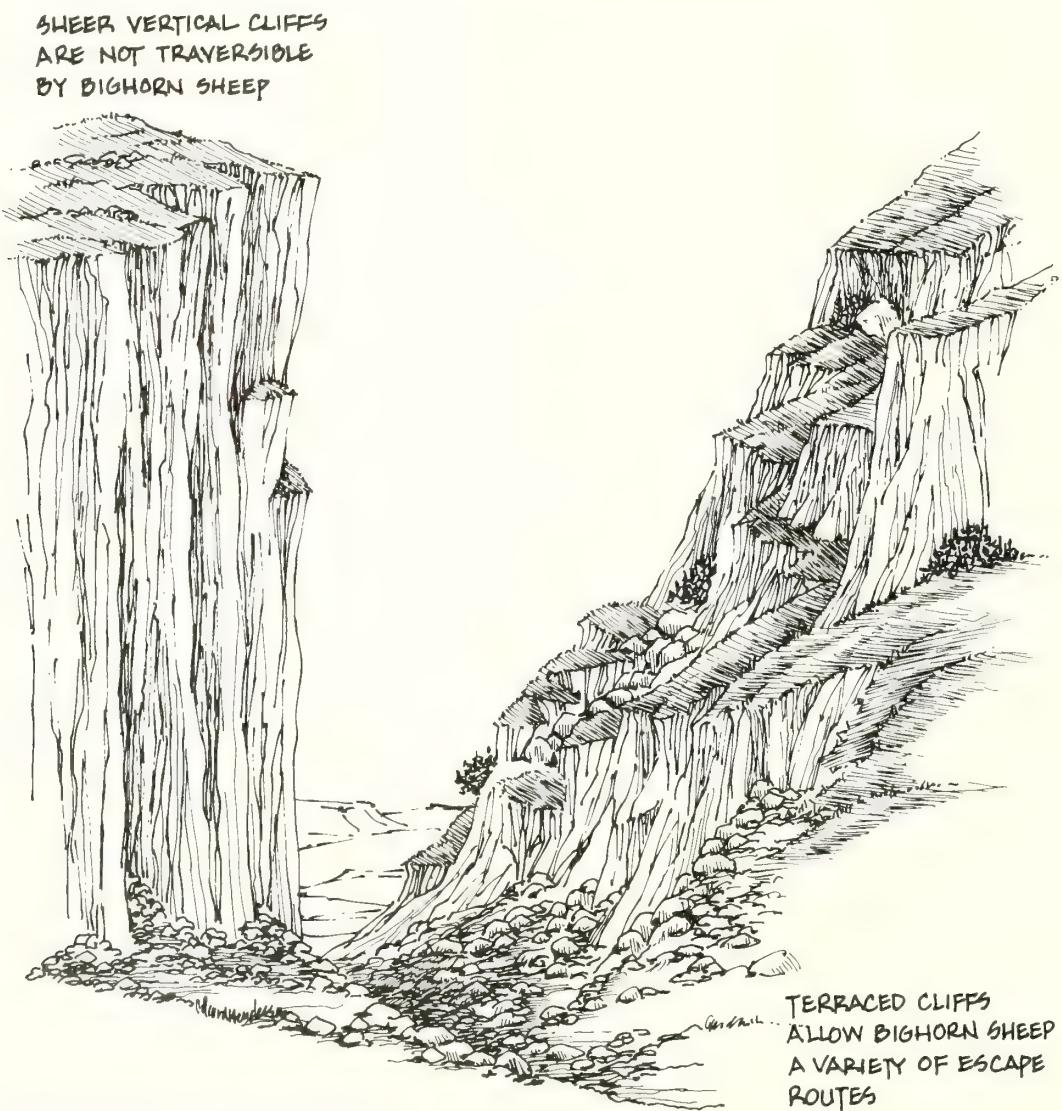


Figure 4.—Comparison of vertical and terraced cliffs as escape terrain for bighorn sheep.

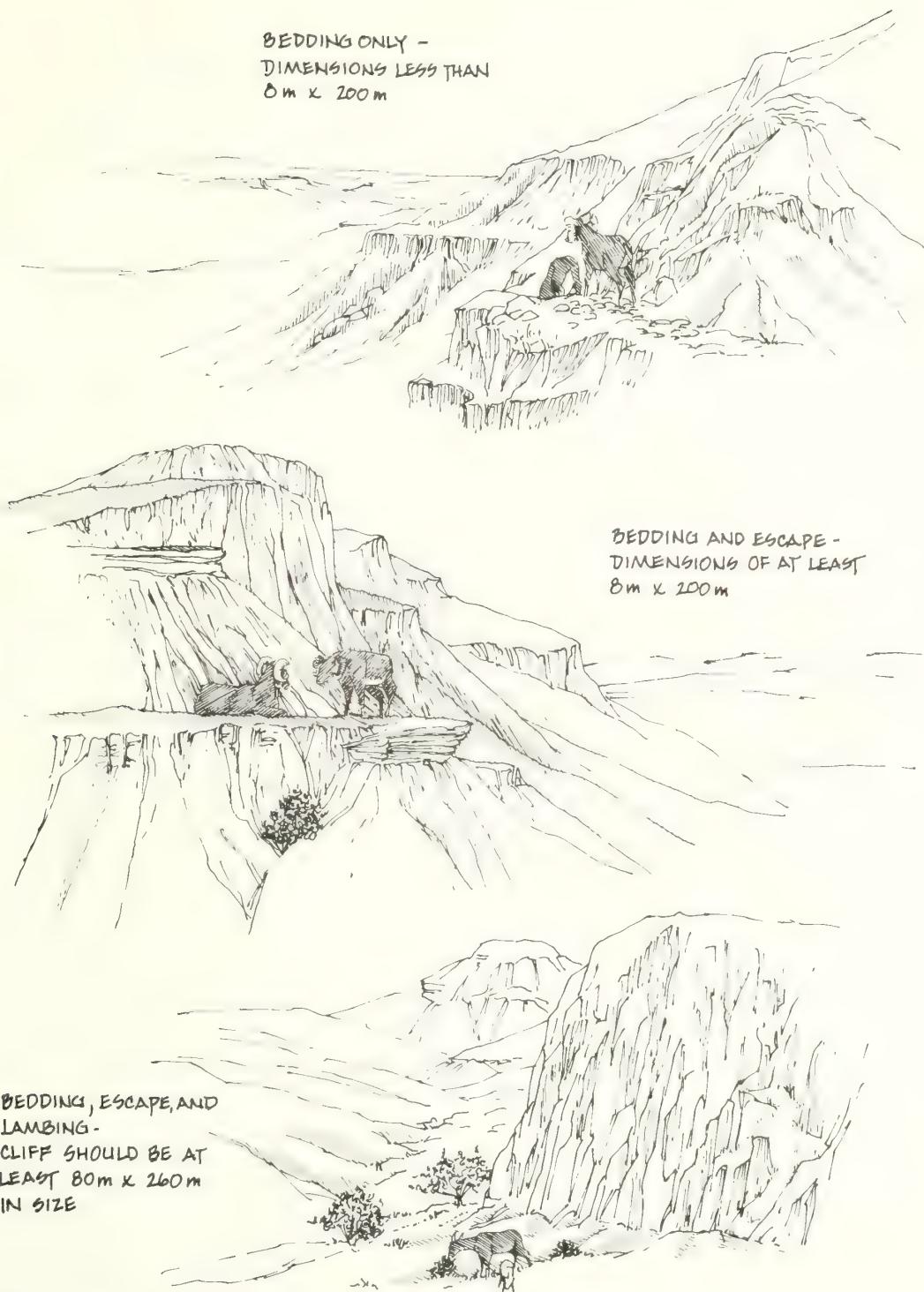


Figure 5.—Size determines the importance of cliffs as habitat for bedding, escape, and lambing.

Cliffs less than 8 meters (26 ft) high by 200 meters (656 ft) long can provide both bedding and thermal areas because they offer some shade in summer and reflect the sun or dissipate absorbed heat in winter. To provide escape terrain cliffs must be at least 8 meters (26 ft) high by 200 meters (656 ft) long or larger (Bailey 1980, McCollough et al. 1980). A series of smaller cliffs with less than 10 meters (33 ft) between them effectively equals a larger cliff. Another way to evaluate cliffs is on the basis of area. Cliffs 0.16 hectare (0.4 acre) and larger can serve as escape terrain as well as bedding and thermal areas, whereas smaller cliffs provide only thermal and bedding areas. To suffice as a lambing area, a cliff or series of cliffs must be at least 2 hectares (5 acres).

Cliffs provide sparse forage and are used for foraging, particularly during lambing season (Van Dyke 1978) and in winter, when forage in adjacent cliffless habitat is unavailable because of crusted snow and ice (Baumann and Stevens 1978, Geist 1971, Geist and Petocz 1977, Shannon et al. 1975). Cliffs do not accumulate as much snow as flatter areas; they reradiate sunrays that melt snow and keep it soft, making it easier for bighorn sheep to paw away snow to obtain forage.

Ewe-lamb groups prefer more rugged topography than ram groups (Blood 1963a, Drewek 1970, Leslie and Douglas 1979) and are more restricted in use of their range (Geist 1971, Leslie and Douglas 1979, Van Dyke 1978). Ram groups will range farther from escape terrain than ewe-lamb groups (Leslie and Douglas 1979). This behavior may be related to their reproductive roles (Geist 1971). Escape terrain may be located above, below, or beside forage and water areas because bighorns can move up or down easily from bedsites to such areas.

The distribution of escape terrain regulates the extent to which other habitat components are used. Most bighorn sheep use forage areas within 0.8 kilometers (0.5 mi) of escape terrain and generally are not seen farther than 1.6 kilometers (1 mi) from escape terrain (Bailey 1980, Denniston 1965, Drewek 1970, Kornet 1978, Leslie and Douglas 1979, McQuivey 1978, Oldemeyer et al. 1971, Van Dyke 1978). Sources

of water more than 0.5 kilometer (0.3 mi) from escape terrain receive limited use (Leslie and Douglas 1979). Distances may increase or decrease, depending on the magnitude and frequency of disturbance sheep receive from humans or predators. In general, use decreases as the distance from escape terrain increases. (fig. 6).

## LAMBING AREAS

Terrain commonly used for lambing is rugged, precipitous and remote (Drewek 1970, Geist 1971, Irvine 1969, Van Dyke 1978) (fig. 7). Such terrain provides pregnant ewes security and isolation for the lambing period, which includes the time lambs need to become strong enough to follow the ewes. Large cliffs and rock outcroppings with sparse cover of trees or shrubs, such as mountainmahogany, afford both thermal and hiding cover to ewes and lambs (Van Dyke 1978). Ideally, adequate forage and water are found within or near lambing areas so ewes with young lambs do not have to venture far to water or forage (Light et al. 1966, 1967). Ewe-lamb groups stay in lambing areas for about a month after lambing before venturing into adjoining, less rugged habitats (Geist 1971, Van Dyke 1978).

Use of lambing areas is frequently traditional but may be altered by lingering deep snow or insufficient forage or water. Lambing occurs on winter, summer, or spring-fall ranges, depending on prevailing environmental conditions, the location of a pregnant ewe at the critical time, and the nature of the available terrain. The birthplace is usually secluded and in rugged terrain. A ewe may travel several kilometers to such an area to give birth (Geist 1971).

Ruggedness and remoteness influence the size of areas required for lambing. If harassment is great, a larger area is more desirable. Ewes appear to select rugged cliffs of at least 2 hectares (5 acres) with dimensions of at least 80 meters (262 ft) by 260 meters (853 ft). Several ewes may lamb within one such area. Adequate size of an area for lambing depends on outside influences. For example, in remote, extremely rugged topography, where harassment is low, only 1 hectare (2.5 acres) may be sufficient.

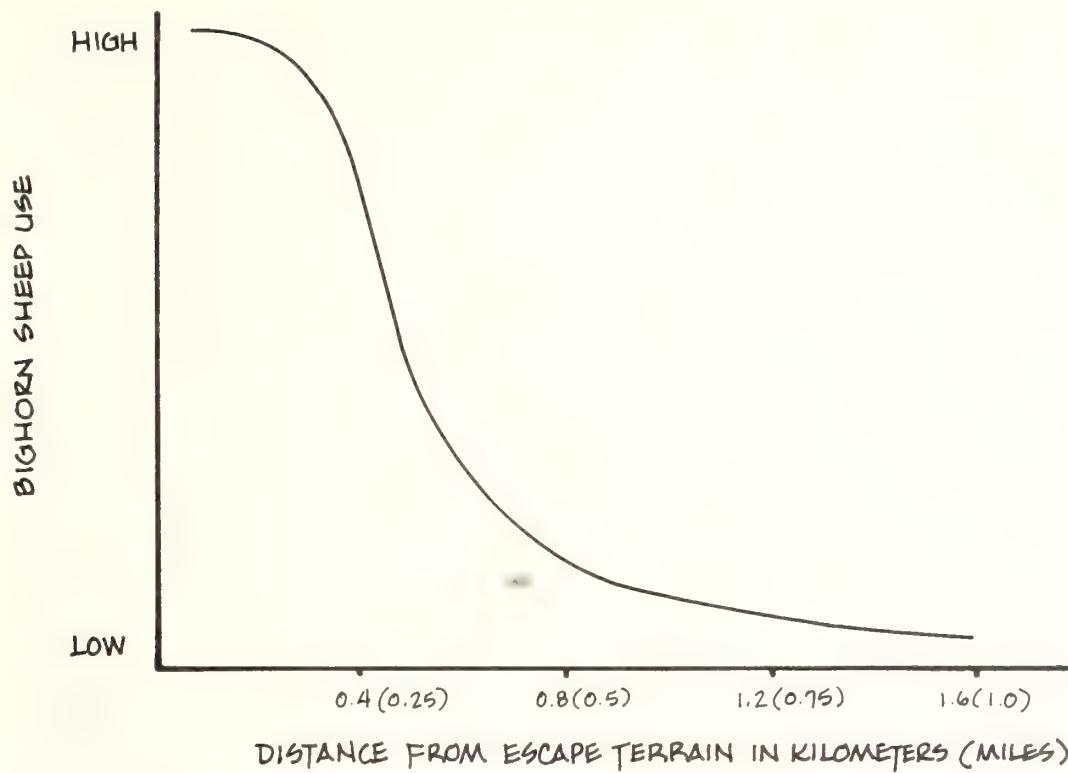


Figure 6.—Distance from escape terrain determines the extent of use.



Figure 7.—Large areas of rugged terrain are preferred for lambing (photo by Walt Van Dyke, courtesy Oregon Cooperative Wildlife Research Unit).



Figure 8.—Plant communities that provide open, low structure are suitable forage areas (photo by Walt Van Dyke, courtesy Oregon Cooperative Wildlife Research Unit).

## FORAGE AREAS

Bighorn sheep tend to forage in open areas with low vegetation, such as grasslands, shrublands, or mixes of these (Geist 1971, Hansen 1980, Sugden 1961, Van Dyke 1978) (fig. 8). Perennial bunchgrasses, which make up a large part of bighorn diet (Barrett 1964, Blood 1967, Browning and Monson 1980, Constan 1972, Demarchi 1965, Geist 1971, McQuivey 1978, Pitt and Wikeem 1978, Sugden 1961, Todd 1972) are an important characteristic of these areas.

The importance of grass in a bighorn sheep's diet was substantiated by a study that compared plant consumption in the Great Basin of Nevada to plant availability (Yoakum 1964). On a year-long basis, more grass was consumed (59 percent) than forbs (32 percent), and shrubs (9 percent) (fig. 9). These percentages are noteworthy because a diet primarily of grass was selected from a cold desert where shrubs predominated. Similar findings were reported by Barrett (1964) in Nevada.

A variety of plant species, common to southeastern Oregon, provide important forage for bighorn sheep (table 1). Lists of plant species can be used to predict the importance of areas for forage, but amounts consumed by bighorn sheep will vary with species composition, range condition, and plant productivity.

Although grass is a staple of the bighorn sheep's diet, a variety of browse and forbs are also used seasonally in varying amounts (Johnson and Smith 1980, Todd 1972). On some ranges where grass or forbs are sparse, diets may consist primarily of browse (Howard and Lorenzo 1975). For the most part, bighorn sheep seem to be opportunistic foragers and, if the physical structure of the habitat is appropriate, can adapt their diet to available plant communities—whether they are dominated by grass, forbs, or shrubs (Browning and Monson 1980, Robinson and Cronemiller 1954).

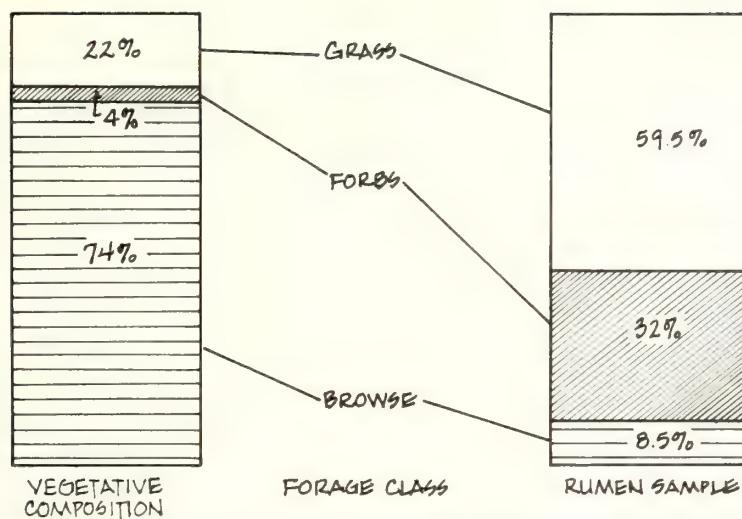


Figure 9.—Comparison of vegetative composition and percent volume of forage classes represented in 12 rumen samples from bighorn sheep on the Silver Peak range, Nevada. (Redrawn from Yoakum 1964)

**Table 1—Plants common to the Great Basin of southeastern Oregon and their seasonal occurrence in the diet of bighorn sheep<sup>1</sup>**

Plant species by forage class	Level of use <sup>2</sup>			
	Winter	Spring	Summer	Fall
<b>Grasses:</b>				
Bearded bluebunch wheatgrass	H	H	M	M
Idaho fescue	M	M	L	M
Bluegrass	L	H	M	M
Bottlebrush squirreltail	L	L	—	L
Prairie junegrass	L	M	L	L
Pinegrass	L	L	L	M
Indian ricegrass	M	M	—	M
Giant wildrye	M	M	M	L
Cheat grass	L	M	—	—
Sedge	L	M	M	L
Thurber's needlegrass	M	M	L	M
Meadow barley	M	—	—	—
<b>Forbs:</b>				
Arrowleaf balsamroot	L	M	L	—
Phlox	—	—	L	L
Milkvetch	L	L	L	—
Lupine	L	L	L	L
Cushion buckwheat	—	M	M	—
Buckwheat	L	L	L	L
Penstemon	L	—	L	—
Lomatium	M	M	—	—
Erigeron	—	M	M	—

**Table 1—Continued**

Plant species by forage class	Level of use <sup>2</sup>			
	Winter	Spring	Summer	Fall
Cobre rockcress	—	M	M	—
Western tansymustard	—	L	—	—
Daggerpod	—	—	M	—
Yarrow	L	L	L	L
Trees and shrubs:				
Big sagebrush	M	L	L	—
Low sagebrush	M	—	M	M
Bud sagebrush	M	L	—	—
Winterfat	M	M	M	H
Rabbitbrush	L	L	L	L
Fourwing saltbush	M	L	L	M
Bitterbrush	H	H	M	—
Mountainmahogany	H	M	L	M
Service berry	L	L	M	L
Elderberry	—	—	L	L
Chokecherry	L	L	L	L
Spiraea	L	L	M	L
Wild rose	L	L	M	L
Ninebark	M	M	M	L
Currant	L	—	—	L
Cinquefoil	—	—	—	M
Willow	L	L	M	M
Snowberry	L	L	M	L
Oceanspray	—	L	L	L
Spiny hopsage	—	—	—	M

<sup>1</sup> Adapted from Blood (1967), Cooperrider et al. (1980), Drewek (1970), Dunaway (1972), Estes (1979), Fairaizl (1978), Hansen (1982), Kornet (1978), Lauer and Peek (1976), McCullough and Schneegas (1966), Pitt and Wikeem (1978), Sugden (1961), Todd (1972), Van Dyke (1978), Yoakum (1966).

<sup>2</sup> L = light, 1 to 5 percent; M = moderate, 6 to 20 percent; H = heavy, 21 to 50+ percent.

Production of forage depends on the amount and timing of precipitation. Managers can estimate the amount of forage available for bighorn sheep only after deducting for plant needs and the amount to be used by other grazing animals.

Forage intake of bighorn sheep is determined by their energy requirements and the availability and quality of forage (Hebert 1973). The amount needed varies with protein content, ambient air temperature, and the sex, age, and activity level of the animal. Apparently consumption does not vary markedly from year to year. Few studies have been conducted to determine the amount of forage required by bighorn sheep, but estimates have been made by Anderson and Denton (1978), Hansen (1980), and Hebert (1973). Such estimates should be used only as a guide in southeastern Oregon and should be updated as more data become available.

Hansen (1980) found that desert bighorn sheep consumed from 1.5 to 1.8 kilograms (3 to 4 lbs) of dry alfalfa per day. Anderson and Denton (1978) in Idaho, and Hebert (1973) in British Columbia, figured the year-round average intake for Rocky Mountain bighorn sheep was 1.44 kilograms per 45.40 kilograms of body weight (3.17 lbs per 100 lbs). A bighorn sheep with an average weight of 56.4 kilograms (124 lbs) would consume 1.77 kilograms (3.90 lbs) of dry matter each day. Once the percentages of grasses, forbs, and shrubs in the diet of sheep are known and the percentages of each that can be provided by the plant communities are known, a more accurate computation of forage available can be made.

Because they depend largely on their acute vision to detect danger, bighorn sheep shun areas of dense, tall vegetation, such as riparian zones and forests (Geist 1971, Kornet 1978, McCann 1956, Oldemeyer et al. 1971, Risenhoover and Bailey 1980, Turner and Weaver 1980) (fig. 10). They avoid extensive forage areas with shrub or canopy cover in excess of 25 percent and shrubs about 60 centimeters (2 ft) high on mild slopes (Van Dyke 1978), whereas, on steep slopes they have been noted to travel through and bed in dense brush (Light et al. 1967).

The availability of water and escape terrain also affects use of forage areas. The more abundant and evenly dispersed these components are, the more uniform use of a forage area will be. Forage areas located farther than 0.8 kilometers (0.5 mi) from escape terrain and farther than 1.6 kilometers (1 mi) from water are little used (Bailey 1980, Blong and Pollard 1968, Denniston 1965, Irvine 1969, Kornet 1978, Leslie and Douglas 1979, McQuivey 1978, Oldemeyer et al. 1971, Van Dyke 1978).

Snow accumulation seems to be the principal factor that triggers bighorn sheep to move from summer to winter ranges (Geist 1971, Geist and Petocz 1977). Where winter and year-long ranges accumulate snow, animals seek areas of least snow depth and paw away snow to uncover forage (Drewek 1970, Geist 1971, Geist and Petocz 1977, Shannon et al. 1975). In Idaho, Lauer and Peek (1976) found that from November through May, 87 percent of bighorn sheep sightings were in areas with less than 5 centimeters (2 inches) of snow, and 97 percent were in areas with less than 16 centimeters (6 inches).

Bighorn sheep prefer green forage and will move up or down or to different aspects to acquire more palatable forage (Hebert 1973, Lauer and Peek 1976, McCann 1956, Shannon et al. 1975, Van Dyke 1978).

Forage areas that present a variety of aspects are preferable because they provide green forage for longer periods. For example, south aspects are generally warmer and provide green forage earlier in spring, while north aspects are generally cooler and provide green forage later in summer. Because they are warmer, south aspects generally have less snow during winter and are selected by bighorn sheep (Bailey 1980, Drewek 1970, Lauer and Peek 1976, Light et al. 1967, McCollough et al. 1980, Van Dyke 1978).

#### **Suitable versus Unsuitable Forage Areas**

It is difficult to classify forage areas as suitable or unsuitable solely on the basis of plant species composition. Topography, substrate, vegetative structure, distance to escape terrain



Figure 10.—Bighorn sheep prefer open areas and shun tall dense stands of trees or shrubs (photo by Walt Van Dyke, courtesy Oregon Cooperative Wildlife Research Unit).

and water, snow depth, and season are also important. Forage areas suitable for bighorn sheep usually have tree or shrub canopy cover of less than 25 percent and shrub height less than 0.6 meters (2 ft). They are less than 1.6 kilometers (1 mi) from water and less than 0.8 kilometers (0.5 mi) from escape terrain. If the above criteria are met, any of the plant communities of southeastern Oregon can provide some forage.

We have rated the major plant communities (in the order listed by Dealy et al. (1981)) according to their suitability as forage for bighorn sheep. On a scale of 1 (low) to 10 (high), ratings are:

Plant Community	Rating
Riparian	5
Quaking aspen/grass	2
Quaking aspen/mountain big sagebrush	2
Curlleaf mountainmahogany/mountain big sagebrush/bunchgrass	5

Curlleaf mountainmahogany/mountain snowberry/grass	4
Curlleaf mountainmahogany/Idaho fescue	4
Curlleaf mountainmahogany/bearded bluebunch wheatgrass-Idaho fescue	4
Curlleaf mountainmahogany/pinegrass	3
Western juniper/big sagebrush/bearded bluebunch wheatgrass	6
Western juniper/big sagebrush/Idaho fescue	6
Basin big sagebrush/bunchgrass	7
Mountain big sagebrush/bunchgrass	9
Subalpine big sagebrush/bunchgrass	9
Wyoming big sagebrush/bunchgrass	8
Three-tip sagebrush/bunchgrass	1
Bolander silver sagebrush/bunchgrass	1
Mountain silver sagebrush/bunchgrass	1
Stiff sagebrush/bunchgrass	7
Low sagebrush/bunchgrass	7
Cleftleaf sagebrush/bunchgrass	1
Black sagebrush/bunchgrass	7
Early low sagebrush/bunchgrass	7
Squaw apple/bunchgrass	2
Black greasewood/bunchgrass	1
Shadscale saltbush/bunchgrass	3
Meadow, seasonally wet	10
Meadow, permanently wet	8
Subalpine bunchgrass	10

Several plant communities in the Great Basin seldom provide forage because of their structure or distance from escape terrain. Communities unsuitable because of structure are: quaking aspen, mountain mahogany, western juniper, and riparian communities dominated by tall shrubs or trees. Communities usually located far from escape terrain and little used for foraging include: squaw apple/bunchgrass, black greasewood/grass, early low sagebrush/bunchgrass, black sagebrush/bunchgrass, Boulders silver sagebrush/bunchgrass, mountain silver sagebrush/bunchgrass, threetip sagebrush/bunchgrass, shadscale saltbush/bunchgrass, and cleftleaf sagebrush/bunchgrass. These communities will get incidental use along migration routes or within established herd ranges.

Successional communities that result from wildfire or seedlings, such as crested wheatgrass, are also encountered in the Great Basin and may provide forage if the location and successional/seral structure are appropriate.

### Summer versus Winter Range

The variation in elevation and topography in the Great Basin creates microsites that differ in accumulations of snow. Some areas may be available for foraging only during a 3-month summer period before snow depth precludes use. In such cases, bighorn sheep may establish patterns of seasonal use of such areas.

Other areas suitable for foraging may accumulate little or no snow and receive year-long use. Areas that provide suitable forage year-round are particularly vulnerable to overuse because of competition among a variety of wild or domestic herbivores.

### WATER

Bighorn sheep use fresh water from many sources. These include dew, streams, lakes, springs, ponds, catchment tanks, troughs, guzzlers, and developed seeps or springs (Blong and Pollard 1968, DREWek 1970, Halloran and Deming 1958, Jones et al. 1957, Sugden 1961, Turner and Weaver 1980, Van Dyke 1978, Welles and Welles 1961, Yoakum et al. 1980). Alkaline waters, however, apparently are not

suitable (Jones et al. 1957). Although the degree of alkalinity tolerated by bighorn sheep is unknown, the maximum dissolved solids suitable for ungulate wildlife has been described as 4,500 p/m (McKee and Wolf 1963). We assume that this figure also applies to bighorn sheep.

The amount of water needed by a bighorn sheep depends on several factors, including: size of the animal, activities, time between waterings, physiological adaptation, environmental stress (humidity and temperature), succulence of ingested forage, and reproductive status (Turner and Weaver 1980). A bighorn sheep ingesting succulent forage on a cool day requires little or no free water, whereas one ingesting dry forage on a hot day needs more free water (Turner and Weaver 1980). There is a greater need for water during periods of physiological stress, such as during rutting or lambing seasons (Wilson 1968).

Desert bighorn sheep have been known to go without water for more than 5 days during summer (Turner and Weaver 1980). They may drink as little water per day as 4 percent of their body weight and as much as 23 percent of their body weight at one time (Turner 1973, Turner and Weaver 1980). Koplin (1960) found that a captive herd of desert bighorn sheep that were fed a dry ration and provided unlimited water drank an average of 4.9 liters (1.3 gal) per day, while free-ranging bighorns were observed to drink as much as 9.5 liters (2.5 gal) per day during summer. Frequency of watering and succulence of vegetation both influence water consumption. A reasonable estimate of the minimum amount of water needed by free-ranging, adult California bighorn sheep of average size (56.4 kilograms, 124 lbs), is 3.5 liters (1.5 gal) per day.

Bighorn sheep spend most of their time within 1.6 kilometers (1 mi) of free water but have been located as far as 3.2 kilometers (2 mi) from it (Blong and Pollard 1968, Irvine 1969, Leslie and Douglas 1979). Water sources more than 0.5 kilometer (0.3 mi) from escape terrain or surrounded by tall dense vegetation are shunned by bighorn sheep (Hansen 1980, Leslie and Douglas 1979, Turner and Weaver 1980).

As the number of water sources declines, habitat use becomes more confined around remaining water sources (Jones et al. 1957, Leslie and Douglas 1979, Welles and Welles 1961). But as precipitation, new plant growth, and cooler temperatures reduce dependence on permanent water, the animals can temporarily extend their range (Leslie and Douglas 1979).

### THERMAL PROTECTION

Elevation, thermal winds, cliffs and rock outcroppings, and trees and shrubs, provide animals the opportunity to minimize stress caused by temperature extremes (fig. 11). Some bighorn sheep herds move to higher elevations

in summer because of available forage and a cooler environment (McCann 1956, Shannon et al. 1975). On subalpine summer ranges where winds were consistent bighorn sheep used little shade.<sup>2</sup> Where summer ranges are below the subalpine zone, bighorn sheep seek shade from geomorphic features to moderate the effects of high temperatures (Leslie and Douglas 1979, Welles and Welles 1961). The amount of energy bighorn sheep expend in thermoregulation will be reduced if the geomorphic features offer a variety of aspects, thus increasing the amount of shade available at different times of day.

<sup>2</sup> Van Dyke, Walter A., wildlife biologist. 1978 data on file at Oregon Department of Fish and Wildlife, Enterprise, Oregon 97828.

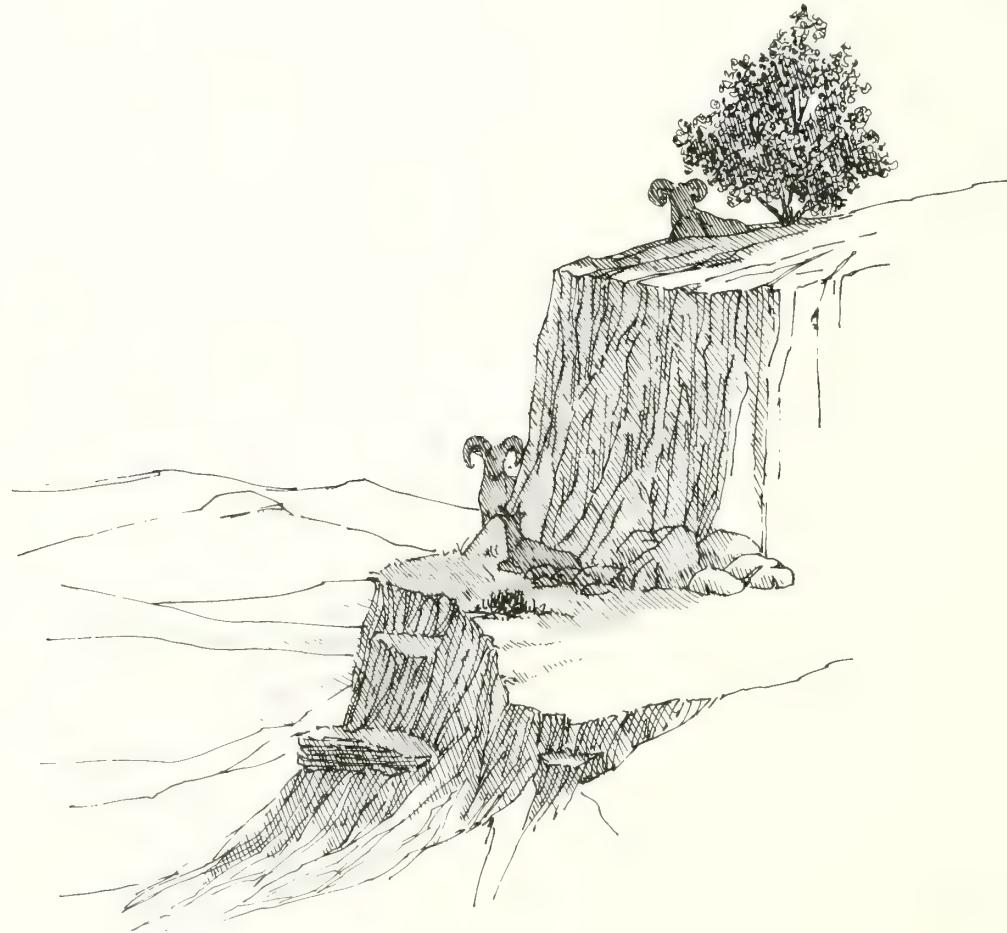


Figure 11.—Cliffs, trees, and shrubs provide shade.

Shrubs and trees with dense canopies provide varying degrees of thermal cover for deer and elk (Thomas et al. 1976). Bighorn sheep normally occupy open areas and consequently do not benefit from the thermal protection offered by tall, dense-canopied vegetation, but they do use trees and shrubs to some extent for this purpose (Hansen 1980, Smith 1954). Mountainmahogany stands, with 25-percent canopy cover, located on cliffs or ground steeper than 35 percent, are apparently used for protection from the sun, especially by ewes during lambing season (Van Dyke 1978). Habitats with dense canopy cover on gentle slopes (less than 35 percent) are used less or even avoided, probably because sheep have poor visibility from within such stands (Van Dyke 1978). In general, use of

trees and shrubs for thermal cover is positively correlated with slope and roughness of terrain and negatively correlated with increasing canopy cover, density, and distance from escape terrain.

Cliffs and rock outcroppings provide shade on hot days and reflect solar radiation during cold periods. Bighorn sheep seek shade during midday and thus conserve body water (Leslie and Douglas 1979) and enhance metabolic efficiency (Moen 1973). Caves are sometimes used for this purpose (Hansen 1980, Leslie and Douglas 1979, Welles and Welles 1961) as well as for lambing (Fairaizl 1978, Hansen 1980) and for shelter during severe storms (Smith 1954) (fig. 12).

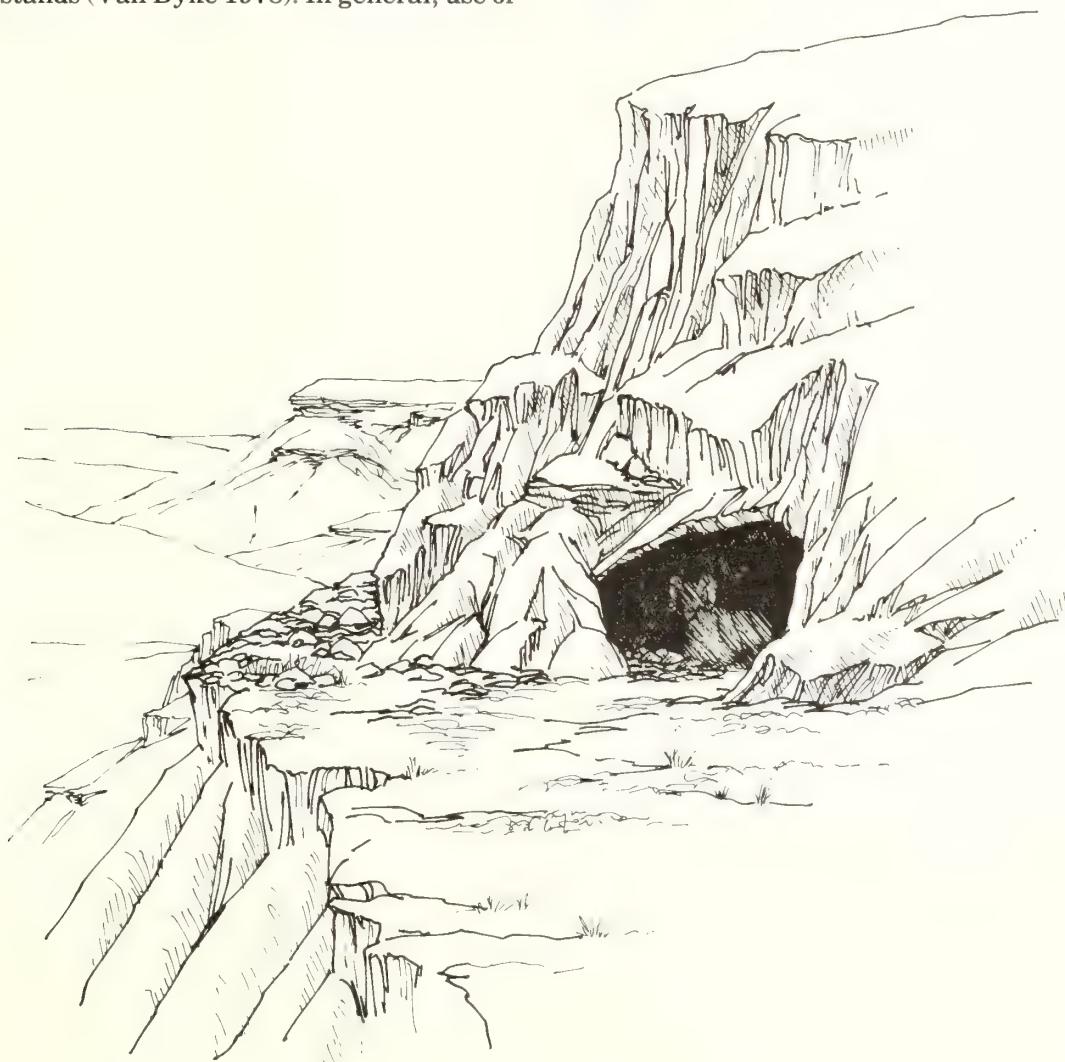


Figure 12.—Caves provide thermal cover and lambing sites.

## RUTTING AREAS

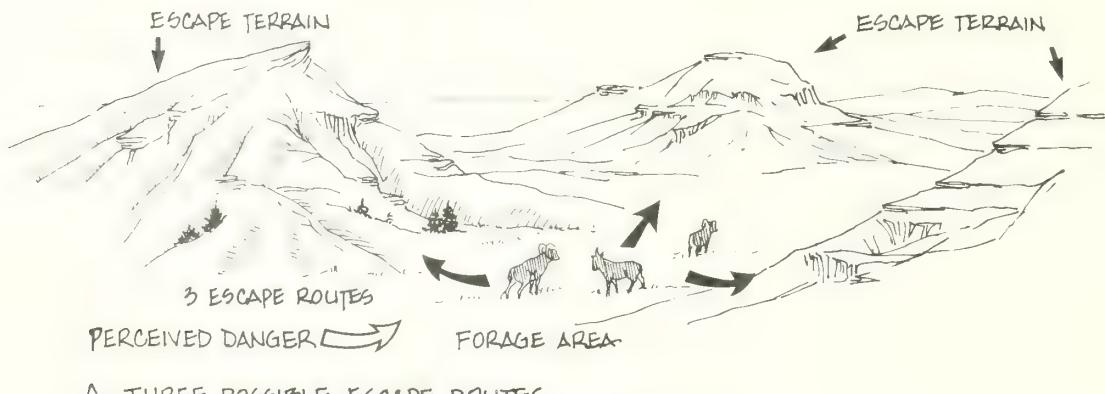
A bighorn sheep herd usually has discrete areas within its range where breeding occurs. A herd may move to traditional rutting areas (Demarchi and Mitchell 1973, Geist 1971) or rams may move to ewe-lamb ranges (Kornet 1978, Van Dyke 1978) for the rut.

During the rut, which occurs from late October to mid-December, the need for forage and water changes. For example, bighorn sheep forage less when rutting (Geist and Petocz 1977) but require more water than usual (Wilson 1968).

## ARRANGEMENT OF HABITAT COMPONENTS

Forage, water, and escape terrain are the most important components of bighorn sheep habitat, but the size, quality, and distribution of these components are also important. In the best habitats, water sources and escape terrain are distributed throughout foraging areas and thus make more grazing available. This intermingling of habitat components reduces pressure on forage near water and escape routes and helps prevent degradation of plant communities.

Forage areas within 0.8 kilometer (0.5 mi) of escape terrain on two or more sides receive more frequent and uniform use than forage areas with escape terrain on only one side (fig. 13).



A. THREE POSSIBLE ESCAPE ROUTES



B. ONLY ONE ESCAPE ROUTE AVAILABLE

Figure 13.—Uniform distribution of sufficient escape terrain is important to bighorn sheep. In A three different escape routes are available; in B only one; consequently, sheep will forage closer to escape terrain in B than in A.

The location of water also influences use of forage areas. If water is distributed at intervals of 3.2 kilometers (2 mi) or less throughout a range and is not farther than 0.5 kilometer (0.3 mi) from escape terrain, optimum use of the habitat can be expected. Sheep will then forage in a circuit, covering more area and putting less grazing pressure on desirable portions of the area.

### SPACE REQUIREMENTS

Bighorn sheep require more than the essential components of appropriately arranged habitat. They also need space. Hansen (1980:74) described space as "... a lack of crowding." The amount of space needed depends on quality of habitat, the amount of negative impact from humans and other animals, and the size of the bighorn herd. Trefethan (1975) suggested that a minimum herd size of 125 animals is necessary for a long-term, viable population. The area required by such a herd depends on the quality of the habitat. Kornet (1978) and Van Dyke (1980) have calculated minimum densities of 13 bighorns per square kilometer (5/sq mi) for herds in the Great Basin of southeastern Oregon. These figures can be used as a guide for estimating the population potential of a given habitat but may exceed the capacity of poorer quality habitat.

Individuals of every bighorn sheep population apparently vary in their tolerance of crowding. For example, individual Rocky Mountain bighorn sheep accustomed to people in a National Park can be photographed from a car window, but individuals unaccustomed to people may flee at the sight of a person or vehicle a mile or more away. Once the limit of tolerance is exceeded, even in otherwise optimum habitat, sheep may abandon an area temporarily or permanently (Light 1971, Spalding and Bone 1969, Wehausen 1980, Welles and Welles 1961). Although bighorn sheep are naturally gregarious, crowding can be detrimental. Crowding may result from a lack of suitable habitat, snow accumulation, structural condition of plant communities, presence of other ungulates, or harassment by humans or predators. The

amount of space needed by bighorn sheep varies with habitat conditions and size of the population. Adverse effects on a sheep population are indicated by abandonment of an area, a drop in productivity, or excessive mortality.

Productivity and survival are enhanced by appropriate interspersion of adequate water, forage areas, and escape terrain, as well as sufficient space, to allow bighorn sheep to use habitat efficiently and minimize energy expenditures and exposure to disturbance.

### Management Tips

The attributes of bighorn sheep habitat can be created, preserved, destroyed, or altered by management action.

### ESCAPE AREAS

Escape terrain is provided naturally by the environment. Without it bighorn sheep will not flourish (Hansen 1980). Rarely can it be enhanced, but it can be altered detrimentally by such activities as mining and constructing roads and reservoirs (fig. 14). In many cases, physical alterations are much less important than the disturbance these alterations introduce. For example, human use of a road along or through a lambing or bedding area eliminates the solitude needed by sheep. Likewise, development of a large reservoir may allow human access by boat to areas formerly remote and inaccessible.

### LAMBING AREAS

The relatively isolated and rugged cliffs cannot be created, but other attributes of prime lambing habitat can be enhanced. Size of lambing areas can be increased by manipulation of adjacent forage areas, development of water sources, and control of competing animal species and people.

The availability of forage and water within and bordering lambing areas is critical. More water can be made available by development or conservation. Forage can be conserved and made available to ewes and young lambs.



Figure 14.—Reservoirs may submerge habitat suitable for bighorn sheep (photo by Walt Van Dyke, courtesy Oregon Cooperative Wildlife Research Unit).

Bighorn sheep will tolerate some human intrusion most of the year, but the lambing period is critical, and the less disturbance the better.

If a herd has traditional areas for lambing (Geist 1971), management should insure that travel corridors to such areas are protected and maintained.

#### FORAGE AREAS

Plant communities vary widely. Differences in species composition and structural features are largely the result of past fire and grazing. Fire tends to reduce the abundance of shrubs and trees, while grasses and forbs are affected less or even increased (Franklin and Dyrness 1973, Graf 1980). Prolonged, heavy grazing by

livestock has the opposite effect (McQuivey 1978); grazing pressure is directed to palatable plants, and unpalatable plants tend to dominate over time (Stoddart et al. 1975).

Dense shrub and tree canopy or undesirable woody plants can be reduced temporarily or eliminated by prescribed fire. Bighorn sheep select forage areas that have been burned (Geist 1971, Graf 1980, Peek et al. 1979, Riggs 1977, Shannon et al. 1975, Stelfox 1971) (fig. 15). Burning may improve plant production and palatability (Peek et al. 1979). Logging, chaining, or spraying should give similar results, but not as quickly, and debris may present a problem (Morgan 1969, Spalding and Bone 1969, Sugden 1961). The goal of any treatment to enhance forage areas is to create the more open habitat preferred by bighorn sheep. The extent to which mechanical methods of vegetative manipulation can be implemented depends on geomorphic features and topography.



Figure 15.—Fire has removed shrub canopy and created a suitable forage area (photo by Walt Van Dyke, courtesy Oregon Department of Fish and Wildlife).

Conflict between bighorns and other grazing species in forage areas appears in two primary forms—social interaction and direct competition. Detrimental social interactions have been documented between bighorn sheep and cattle (Dean 1977, Irvine 1969, Russo 1956, Wilson 1968) and goats (Russo 1956, Wilson 1968). When cattle or goats occupy ranges used by bighorn sheep, the sheep move to less desirable areas or concentrate on the remaining habitat. If bighorn sheep are to be featured, socially conflicting species may have to be removed. Fortunately, the nature of bighorn sheep and the severe topography they inhabit usually results in their isolation from domestic livestock. Adverse social interactions between bighorn sheep and mule deer, elk, or pronghorns have not been reported in the literature.

Whenever two or more species of grazing animals are found in the same area, competition for forage is possible, but inherent characteristics usually allow species to partition a particular

resource. Competition between two species may be caused by inclement weather, the introduction of exotic ungulates, or the improper management of animal numbers—domestic or wild (Crump 1971, Sugden 1961, Weaver 1972). There are documented accounts of competition for forage between bighorn sheep and cattle (Blood 1961, Demarchi 1965, Demarchi and Mitchell 1973, Lauer and Peek 1976, Morgan 1968, Stelfox 1971); horses (Crump 1971; McQuivey 1978; Schallenberger 1965; Stelfox 1971, 1976; Woodgerd 1964); elk (Buechner 1969, Cowan 1947, Schallenberger 1965, Stelfox 1971); deer (Berwick 1968, Buechner 1960, Cooperrider 1969, Drewek 1970, Morgan 1968, Schallenberger 1965, Stelfox 1971); and domestic sheep (Morgan 1968, Uhazy et al. 1971). Most of the competition was on bighorn winter ranges. In the case of domestic livestock, competition for forage resulted from livestock grazing on bighorn winter ranges during summer.

The result of competition was generally twofold— inadequate forage for one or more species and severe impairment of range quality. Forage allocation and grazing management to accommodate bighorn sheep and other grazers has been achieved by reducing the number of domestic or wild ungulates and/or controlling the intensity of domestic livestock grazing and season of use (Crump 1957, 1971; Stelfox 1971). Similar solutions can be implemented on other seasonal ranges. Livestock grazing on bighorn range has been completely stopped in some areas (Lange et al. 1980).

Competition for forage is more pronounced where livestock grazing occurs on ranges of non-migratory bighorn sheep. Because of social conflicts and the forage needs of bighorn sheep, it is preferable that domestic livestock not be grazed within the year-long home ranges of bighorn sheep. If grazing by livestock must occur, it should be confined to only a portion of the bighorn range and periodically moved in a planned grazing system (Anderson 1967). Such action will minimize competition between domestic livestock and bighorn sheep (Anderson and Scherzinger 1975).

The best way to assure an adequate food source for bighorn sheep may be to reserve forage areas adjacent to their escape terrain, lambing areas, and water sources. Allowing domestic livestock in such areas risks depletion of the food supply, which may be limited (Crump 1957, 1971; Stelfox 1971). Food supplies may also be limited by the bighorn sheep's inability or unwillingness to readily change home ranges (Geist 1971).

If domestic livestock are grazed on bighorn sheep range, their use should alternate with sheep use. Livestock grazing must be done with utmost care to insure: adequate forage supplies for the sheep at the appropriate season, protection of the range vegetation and soils, and minimum harassment of the sheep. These objectives may be attained by fencing, limiting numbers of livestock, grazing on rotational or seasonal systems, placing salt and water to attract livestock away from bighorn forage, and using fertilizers to improve palatability of forage for livestock (Bear 1978, Bodie and Hickey 1980,

Martin 1978, McCollough et al. 1980, Meehan and Platts 1978, Skovlin 1965, Stoddart et al. 1975). If the management priority is the welfare of bighorn sheep, other wild or feral ungulates (primarily deer, elk, and horses) may have to be reduced by killing or capture and removal to maintain sufficient forage for bighorn sheep and minimize adverse social interactions.

Managers will often be faced with problems caused by the effects of fences on bighorn sheep. Fences restrict movement and cause mortality, especially of rams that get their horns tangled in the wire (Welsh 1971). Helvie (1971) has given guidelines for building fences in areas occupied by bighorn sheep. Fences should not be constructed with woven wire, but with smooth or barbed wire, pipe, rails, or poles. Helvie also recommended that posts or stays be placed no farther apart than 3 meters (10 ft). Wires should be spaced 51, 89, and 99 centimeters (20, 35, and 39 inches) above the ground, and poles, pipes or rails 51, 97, and 112 centimeters (20, 38, and 44 inches) above the ground (fig. 16). Such spacing allows bighorns to go through or under a fence while restricting livestock movement.

Another type of fence that can be used is the lay-down fence (fig. 16). It can be erected when cattle are present and dropped flat when bighorn sheep are present.

Use of fences should allow bighorn sheep to move through an area while keeping cattle on designated pastures.

In selecting objectives for managing a range for bighorn sheep, a manager should answer three questions: (1) What are the requirements of the particular bighorn sheep population? (2) Do other wild, feral, or domestic ungulates occupy the area with the sheep? and (3) Do these occupants alter the habitat in ways that are detrimental to the sheep? Bighorn sheep are a much more sensitive part of the management equation than mule deer, elk, feral horses, or domestic livestock. Bighorn sheep are comparatively rare. They occupy habitats that are sensitive to alteration, and they respond adversely to disturbance. Unless they are given primary emphasis, bighorn sheep are unlikely to become established or to continue in existence.

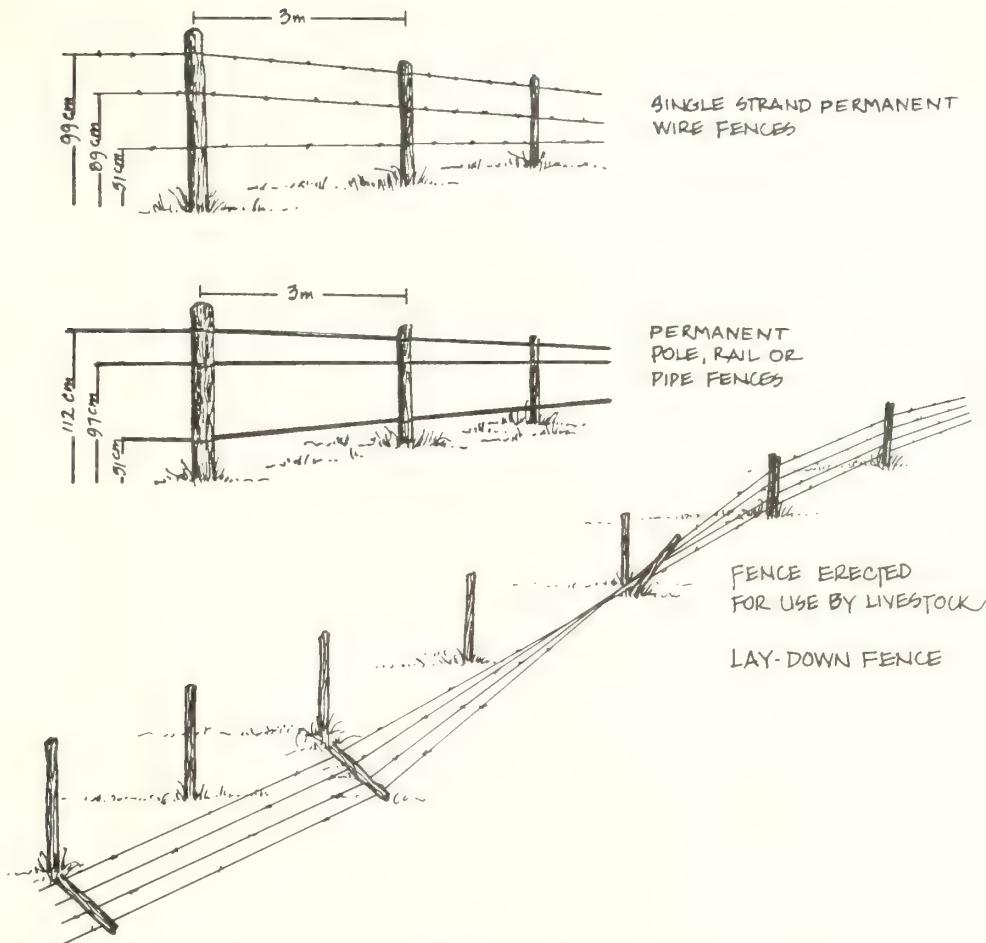


Figure 16.—Types and dimensions of fences that can be used on bighorn sheep range.

Bighorn sheep ranges, present and potential, occupy such a small percentage of area suitable for grazing domestic livestock, that reserving forage for bighorn sheep will have little overall impact on domestic livestock (fig. 17).

## **WATER**

If water is absent or limited on otherwise suitable bighorn sheep range, steps can be taken to conserve existing water and to make new sources available under circumstances that encourage bighorn sheep use.

If water is not available from permanent, natural sources, impoundments can be developed to provide it. Water from seeps, low-flow springs, seasonal springs, and seasonal

streams can be collected, stored, and conserved to make it available during critical periods of the year (Halloran and Deming 1958, Jones et al. 1957, Wilson 1977, Yoakum et al. 1980).

If water from runoff, springs, or seeps is absent, guzzlers with large collection aprons (Yoakum et al. 1980) can be used to collect it (fig. 18). Water sources that are constructed to collect runoff or seepage water will be most beneficial in ravines or crevices where such water is likely to be available. It may be desirable to pipe water from a development to troughs—to prevent mucking—or to locations better suited for use by bighorn sheep.

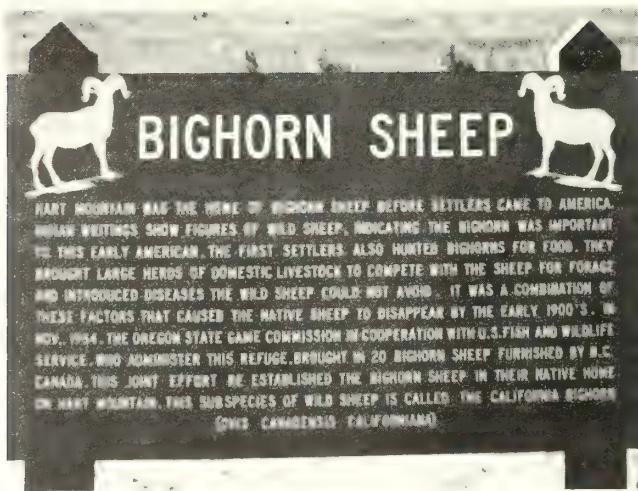


Figure 17.—In the future, bighorn sheep may depend on parcels of land set aside and managed primarily for them (photo by Alan Sands).

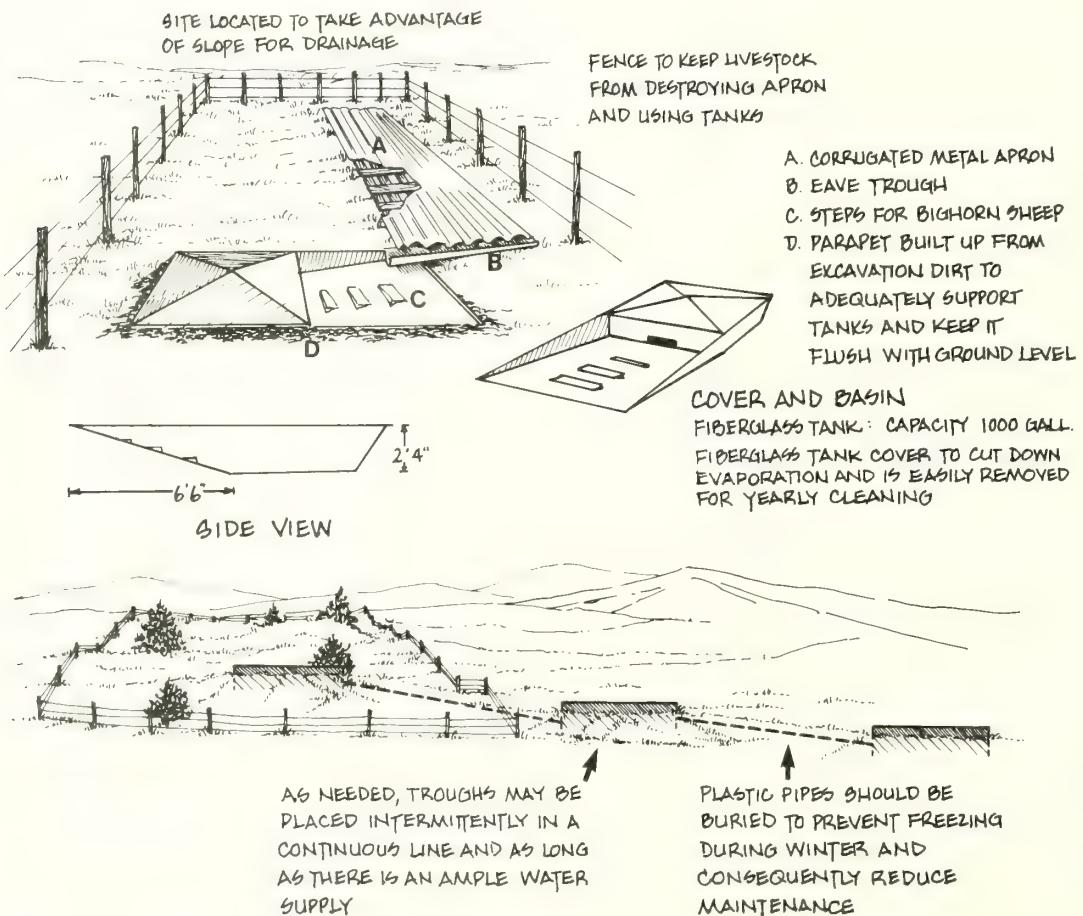


Figure 18.—Water developments that can be installed on bighorn sheep ranges include collection aprons with storage tanks and springs or seeps developed with troughs. (Adapted from Yoakum et al. 1980)

In the Great Basin, naturally occurring water is least available during hotter portions of the year, after surface water is gone, so impoundments should provide water during this period. Where possible, they should be shaded from the sun to reduce evaporation. Development of "permanent" water sources can make available areas that have all the other components of bighorn sheep habitat (Jones et al. 1957). During the colder portions of the year, water should be available in locations where it is least likely to freeze and where the animals are most likely to be, such as on south-facing slopes.

Care should be taken to ensure that watering devices will not trap or injure bighorn sheep (Mensch 1969). Periodic maintenance will be needed to keep such devices functioning (Jones et al. 1957).

The most desirable placement of water sources is at intervals of 3.2 kilometers (2 mi) and within 0.5 kilometer (0.3 mi) of escape terrain. Larger intervals will not allow bighorn sheep to use the habitat uniformly and will impose stress on the animals.

Creating water sources may increase conflict between bighorn sheep and other ungulates or people. Conditions detrimental to bighorn sheep that may result include severe grazing (Stelfox 1971); the potential for exchange of parasites or disease between bighorns and other ungulates, particularly domestic sheep (Bunch et al. 1978, Samuel et al. 1975); and degradation of water quality by mucking or defecation (Welles and Welles 1961; Wilson 1968, 1977).

Steps can be taken to remedy such problems. Conflicting species can be removed by trapping or killing. Existing waterholes can be fenced to exclude conflicting ungulate species (Morgan 1969, Schallenberger 1965, Trefethan 1975, Wilson 1977). Water sources can be developed in rugged topography that only bighorn sheep frequent, or other ungulates can be excluded by fences while bighorn sheep have access via escape terrain (Halloran and Deming 1958) (fig. 19). Water sources for livestock can be installed in areas distant from bighorn sheep habitat to attract livestock away from such habitat (McCollough et al. 1980).

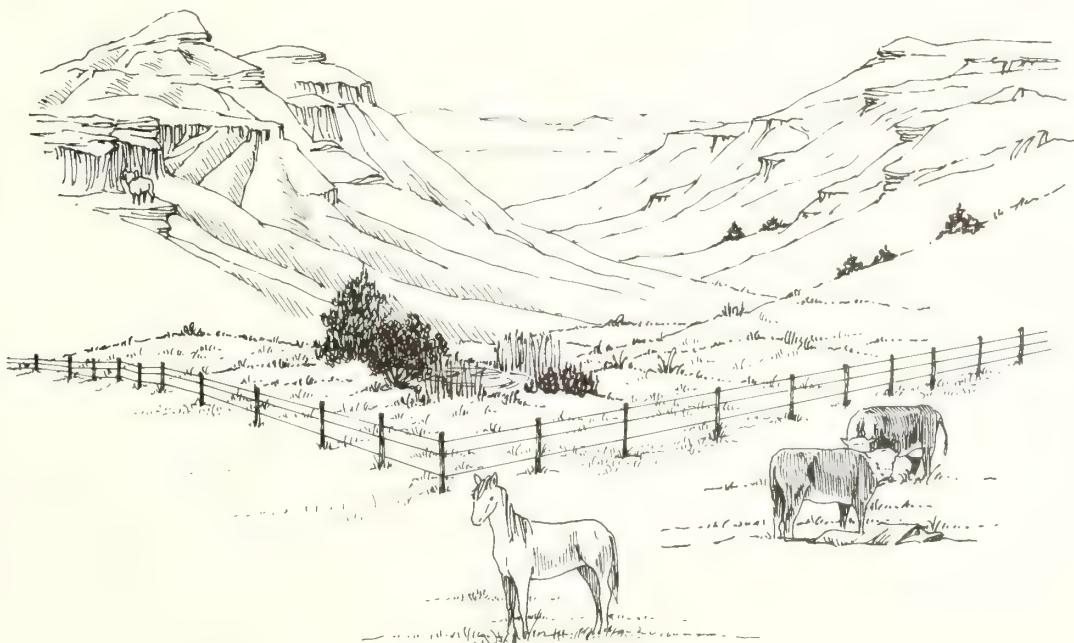


Figure 19.—Domestic and feral ungulates can be fenced away from a water source to preserve it for bighorn sheep.

Regular human activity can cause bighorn sheep to alter or terminate their use of water sources (Blong and Pollard 1968, Buechner 1960, Welles and Welles 1961). Where this occurs, special restrictions can be implemented for people and their equipment (Hicks and Elder 1979). For best results, water should be conserved and reserved for bighorn sheep through proper location and control of conflicting species.

### **THERMAL FACTORS**

Thermal protection for bighorn sheep comes from two primary sources—vegetation and geomorphic features. These sources provide shade or reradiate heat. A manager must work with existing geomorphic features because they cannot be produced. Their effectiveness, however, can be enhanced by restricting human activity and insuring that water and forage are provided in close proximity to reduce travel for bighorns.

Where trees are lacking, or where trees and shrubs have dense or extensive canopies that discourage use by bighorn sheep, a manager can improve the thermal qualities or use of existing stands. Canopies that are too dense can be opened by prescribed burning or thinning. If, on the other hand, additional cover is needed, species compatible with the site, such as mountainmahogany or juniper, can be planted and livestock fenced out to allow seedlings to become established. In arid or semi-arid areas, growing trees or tall shrubs is a relatively slow process and providing thermal cover may require 10 to 30 years.

### **RUTTING AREAS**

Human disturbance is detrimental to breeding. Restricting the use of roads, trails, or areas open to travel by people and controlling other management activities helps insure that breeding progresses normally. The rut is a critical part of the bighorn sheep's life cycle, and solitude is conducive to successful breeding. Excessive disturbance in any form may cause a decline in productivity.

If a bighorn sheep herd migrates to traditional areas for the rut (Geist 1971), it is of utmost importance that travel corridors to such areas be protected and maintained.

### **PARASITES AND DISEASES**

Some of the factors responsible for the large reduction in the number of bighorn sheep since the turn of the century have been practically eliminated. Indiscriminate shooting has been curbed by tightly regulated and enforced hunting systems. In some cases, proper allocation of forage between bighorn sheep and other grazers has made sufficient forage available for bighorn sheep (Crump 1957, 1971; Stelfox 1971). But, parasites and diseases are still a threat.

Numerous parasites and diseases have been documented in bighorn sheep (Allen 1971, Becklund and Senger 1967). Species-specific parasites, such as lungworms and intestinal nematodes that have evolved with bighorn sheep play a natural role in regulating numbers and rarely decimate entire populations (Blood 1963b, Buechner 1960, Forrester 1971, Kistner et al. 1977, McCullough and Schneegas 1966). Other co-evolved parasites specific to bighorn sheep may not be detrimental to herd health (Allen 1971, Samuel et al. 1978).

Although species-specific parasites and diseases may threaten bighorn sheep populations, some of the parasites and diseases contracted from domestic livestock are a greater threat. Although most parasites and diseases carried by domestic livestock do not appear to have undesirable effects on bighorn sheep, others apparently have been responsible for decimating entire herds. In most of these instances there was no direct evidence that domestic livestock were the source of the disease or parasite, but conditions prevailing at the time suggested that domestic livestock were the source. For example, bluetongue, a common disease of domestic sheep usually transmitted by insect vectors (Trainer 1970), was responsible for the death of a captive bighorn sheep in Texas (Robinson et al. 1967). Subsequently, the captive herd was

nearly wiped out by the disease.<sup>3</sup> Bluetongue also caused the death of several bighorn sheep from a herd in northern California (Campbell 1980). In both instances, domestic sheep had ranged in areas adjacent to those used by the bighorn sheep. Entire herds in California and Washington have recently been lost to bacterial pneumonia. The source of the disease probably was domestic sheep (Campbell 1980, Foreyt and Jessup 1982, Jessup 1980).

The sheep bot fly, usually associated with domestic sheep and occasionally with domestic goats and deer (Capelle 1971), has been reported in bighorn sheep (Capelle 1966). It was recently identified as a cause of mortality in desert bighorn sheep (Bunch et al. 1978). To date, there has been no satisfactory way to control the spread of the bot fly, whose life cycle can be completed in bighorn sheep.

The scab mite, which causes psoroptic mange, apparently can be carried by domestic livestock and at the turn of the century was thought to be responsible for significant losses of bighorn sheep. Although psoroptic mange has since been considered eradicated or controlled, it has recently been associated with losses of desert bighorn sheep in New Mexico (Lange 1980, Lange et al. 1980, Williams 1980). Because this mite can still have drastic effects on herds of bighorn sheep, the best prevention is to eliminate opportunities for its transmission from domestic livestock.

Contagious ecthyma (soremouth) has commonly been diagnosed in domestic and bighorn sheep (Blood 1971, Campbell 1980, Samuel et al. 1975). Although some biologists think this condition has minimal impacts on bighorn sheep (Blood 1971), it has been responsible for numerous deaths, primarily of lambs (Campbell 1980).

A species of lungworm common to domestic sheep was responsible for deaths in a captive herd of bighorn sheep (DeMartini and Davies 1976, 1977). The animals died from pneumonia that developed only after they were infected by the lungworm.

Other parasites and diseases borne by domestic sheep that can be harmful to bighorn sheep include: helminths (Uhazy and Holmes 1970); coccidia (Uhazy et al. 1971); and pneumonia (DeMartini and Davies 1976, Howe et al. 1966, Parks et al. 1972). Pneumonia is serious only when bighorn sheep have suffered lung tissue damage or are subject to unusual physiological or psychological stress (DeMartini and Davies 1977, Woolf and Kradel 1973). Any herd of bighorn sheep can become stressed—by predators, by association or competition with livestock or humans, or by inclement weather (Foreyt and Jessup 1982, Parks et al. 1972).

Therefore, if bighorn sheep are to have the best opportunity to survive, they should be spatially separated as far as possible from domestic livestock to prevent contamination (Foreyt and Jessup 1982, Jessup 1980, Robinson et al. 1967) (fig. 20). This is especially important where flying insect vectors are involved. Attractants such as salt stations should be used sparingly because they tend to concentrate use by all ungulates and increase the possibility of disease transfer (Blood 1971, Samuel et al. 1975). Likewise, water sources and feeding stations should be placed so they are never used at any time by both domestic and bighorn sheep (fig. 21).

Pesticides can be used to retard or control some outbreaks of disease (Bunch et al. 1978). For example, the lungworms of bighorn sheep, and the land snails that are the lungworms' intermediate hosts, can be controlled by administering drugs or molluscicides and larvicides to animals or by applying the treatment to a range (Hibler 1976, 1977; Hibler and Spraker 1976). Bighorn sheep infested with scab mites have been injected with drugs to kill the mites and temporarily prevent reinfestation (Williams 1981). The difficult step is to catch the bighorns so they can be treated.

<sup>3</sup> Thomas, Jack Ward, wildlife biologist, Pacific Northwest Forest and Range Experiment Station, La Grande, Oregon, personal communication.



Figure 20.—Domestic sheep should be kept as far as possible from areas inhabited by bighorn sheep (photo by Walt Van Dyke, courtesy Oregon Department of Fish and Wildlife).



Figure 21.—Water sources and salt stations should be located so they are not used by both bighorn sheep and livestock (photo by Walt Van Dyke, courtesy Oregon Department of Fish and Wildlife).

## PREDATION

Important predators of bighorn sheep in the Great Basin include cougar, bobcat, coyote, and golden eagle. Of these, the cougar is considered the most capable of killing bighorn sheep (Buechner 1960, Smith 1954). Most authors addressing this topic indicate that the number of animals taken by predators is usually of little consequence to healthy populations of bighorn sheep (Buechner 1960). Losses frequently can be attributed to a single predatory animal that can be selectively removed (Blaisdell 1961). Predators are most effective when locations of escape terrain or water limit sheep movement and allow predators to concentrate hunting effort in a small area (Blaisdell 1961, Light et al. 1967). The impact of predation must be evaluated on a herd-by-herd basis and appropriate action taken.

## HUMAN IMPACTS

Even if all the individual components of a habitat are satisfactory, the habitat as a whole will be unsuitable for bighorn sheep if human use is excessive. Human intrusion reduces the number of bighorn sheep, by causing sheep to reduce or terminate their use of prime habitat, stop migration, or split large existing herds into smaller herds (Dunaway 1971, Ferrier 1974, Horejsi 1976, Jorgensen and Turner 1973, Light 1971, Rutherford 1972, Spalding and Bone 1969, Weaver 1972, Wehausen 1980, Welles and Welles 1961). Human activities responsible for declines in sheep use include hiking and backpacking (Blong and Pollard 1968, Dunaway 1971, Nelson 1966, Wehausen 1980, Welles and Welles 1961), snow skiing (Light 1971), and water skiing and fishing (Ferrier 1974). Additional causes of declines are motorbiking (DeForge 1972), driving 4-wheel vehicles (Jorgensen and Turner 1973), construction and use of highways (Ferrier 1974), urban development (Ferrier 1974), and recreational development (Spalding and Bone 1969). When bighorn sheep are pushed from prime to marginal habitat, mortality usually increases and productivity decreases (Thorne et al. 1978).

Some herds of bighorn sheep have become conditioned to human activity (Hicks and Elder 1979). For most herds, however, the amount of human activity they can stand varies with the herd and the type and amount of activity (Dunaway 1971, Light 1967, McQuivey 1978). Some herds have become conditioned to human activity (Hicks and Elder 1979). For example, biweekly encounters between bighorn sheep and humans may have no measurable effects; whereas, daily encounters may cause sheep to discontinue use of an area.

Roads have an important association with human activity (Ferrier 1974). Although roads themselves are not necessarily detrimental to bighorn sheep, they greatly facilitate human access (fig. 22). Backcountry roads that receive little use may have little or no effect, but other roads have caused bighorn sheep to alter traditional migration routes (Ferrier 1974). Roads must be individually evaluated. If human access is detrimental, it can be controlled through road closures. When bighorn sheep are on summer range, human use of roads on their winter range will have little effect. The opposite is also true. Where bighorn sheep occupy year-long ranges, permanent road closures should be considered.

Road closures may not be feasible when bighorn sheep ranges lie adjacent to major roads or highways, but restricting off-road use of such areas may be feasible.

Remote, roadless bighorn sheep ranges sometimes receive heavy daily use from hikers and backpackers. In such situations, closures or restrictions may be required.

Land developments such as resorts, housing subdivisions, private dwellings, and hydroelectric installations, and activities such as mining, logging, and road construction, cause bighorn sheep to alter their use of habitat (Ferrier 1974, McQuivey 1978, Sugden 1961, Yoakum 1971). If the management objective is to maintain bighorn sheep, a careful evaluation of potential habitat alteration and human activity is critical to the planning process. For the most part, bighorn sheep now exist in the wild because of human decisions, and the fate of the species in the Great Basin of southeastern Oregon and other areas will be determined by future management of public lands (fig. 23).



Figure 22.—Roads through prime bighorn sheep habitat increase human access and associated negative impacts (photo by Walt Van Dyke).



Figure 23.—The future of bighorn sheep depends on the response of people to the bighorns's needs (photo by Walt Van Dyke, courtesy Oregon Cooperative Wildlife Research Unit).

## Literature Cited

- Allen, R. W.  
1971. Present status of lungworm and tapeworm infections in bighorn sheep. *Trans. Desert Bighorn Counc.* 15:7-11.
- American Ornithologist's Union.  
1957. Checklist of North American birds. 5th ed. 691 p. Port City Press, Inc., Baltimore, Maryland.
- Anderson, E. W.  
1967. Grazing systems as methods of managing range resources. *J. Range Manage.* 20(6):383-388.
- Anderson, E. W., and R. J. Scherzinger.  
1975. Improving quality of winter forage for elk by cattle grazing. *J. Range Manage.* 28(2):120-125.
- Anderson, L. D., and J. W. Denton.  
1978. Determining forage consumption rates for big game. Bureau of Land Manage., Salmon, Idaho. 5 p.
- Bailey, J. A.  
1980. Trickle Mountain forage allocation research. U.S. Dep. Inter. Bur. Land Manage. Rep. No. 5, 30 p. Denver Service Center, Denver, Colo.
- Bailey, V.  
1936. The mammals and life zones of Oregon. North Am. Fauna No. 5, 416 p. U.S. Gov. Print. Off., Washington, D.C.
- Barrett, R. H.  
1964. Seasonal food habits of the bighorn at the Desert Game Range, Nevada. *Trans. Desert Bighorn Counc.* 8:85-93.
- Baumann, T. G., and D. R. Stevens.  
1978. Winter habitat preferences of bighorn sheep in the Mummy Range, Colorado. In Proceedings of the 1978 nothern wild sheep and goat conference, p. 320-330. British Columbia Fish and Wildl. Branch. Penticton.
- Bear, G. D.  
1978. Evaluation of fertilizer and herbicide applications on two Colorado bighorn sheep winter ranges. Colo. Div. Wildl. Rep. No. 10, 75 p. Denver.
- Becklund, W. W., and C. M. Senger.  
1967. Parasites of *Ovis canadensis* in Montana with a checklist of the internal and external parasites of the Rocky Mountain sheep in North America. *J. Parasitol.* 53:157-165.
- Berwick, S. H.  
1968. Observations on the decline of the Rock Creek, Montana, population of bighorn sheep. M.S. thesis. Univ. Montana, Missoula. 245 p.
- Blaisdell, J. A.  
1961. Bighorn-cougar relationships. *Trans. Desert Bighorn Counc.* 5:42-46a.
- Blong, B., and W. Pollard.  
1968. Summer water requirements of desert bighorn in the Santa Rosa Mountains, California, in 1965. *Calif. Fish and Game* 54(4):289-296. Sacramento.
- Blood, D. A.  
1961. An ecological study of California bighorn sheep *Ovis canadensis californiana* (Douglas) in southern British Columbia. M.S. thesis. Univ. British Columbia, Vancouver. 127 p.
- Blood, D. A.  
1963a. Some aspects of behavior of a bighorn herd. *Can. Field-Nat.* 77(2):77-94.
- Blood, D. A.  
1963b. Parasites from California bighorn sheep in southern British Columbia. *Can. J. Zool.* 41(6):913-918.
- Blood, D. A.  
1967. Food habits of the Ashnola bighorn sheep herd. *Can. Field-Nat.* 81(1):23-29.
- Blood, D. A.  
1971. Contagious ecthyma in Rocky Mountain bighorn sheep. *J. Wildl. Manage.* 35(2):270-275.
- Bodie, W. L., and W. O. Hickey.  
1980. Response of wintering bighorn sheep to a rest-rotation grazing system in central Idaho. In Proceedings of the biennial symposium of the northern wild sheep and goat council, p. 60-69. Idaho Dep. Fish and Game. Salmon.
- Browning, B. M., and G. Monson.  
1980. Food. In The desert bighorn, its life history, ecology, and management, p. 80-99. G. Monson and L. Sumner, eds. Univ. Arizona Press, Tucson.
- Buechner, H. K.  
1960. The bighorn sheep of the United States, its past, present, and future. *Wildl. Monogr.* No. 4, 174 p.
- Bunch, T. D., S. R. Paul, and H. McCutchen.  
1978. Chronic sinusitis in the desert bighorn (*Ovis canadensis nelsoni*). *Trans. Desert Bighorn Counc.* 22:16-20.
- Campbell, D.  
1980. Lava Beds Bighorn:—from 10 to 43 to 0. *Outdoor Calif.* 41(6):5-7.
- Capelle, K. J.  
1966. The occurrence of *Oestrus ovis* L. (Diptera: Oestridae) in the bighorn sheep from Wyoming and Montana. *J. Parasitol.* 52(3):618-621.
- Capelle, K. J.  
1971. Myiasis. In Parasitic diseases of wild animals, p. 279-305. J. W. Davis and R. C. Anderson, eds. Iowa State Univ. Press, Ames.
- Chapman, Joseph A., and George A. Feldhamer.  
1982. Wild mammals of North America: biology, management, and economics. 1,147 p. The Johns Hopkins Univ. Press, Baltimore, Maryland.
- Constan, K. J.  
1972. Winter foods and range use of three species of ungulates. *J. Wildl. Manage.* 36(4):1068-1076.
- Cooperider, A. Y.  
1969. Competition for food between mule deer and bighorn sheep on Rock Creek winter range, Montana. M.S. thesis. Univ. Montana, Missoula. 92 p.

- Cooperrider, A. Y., S. A. McCollugh, and J. A. Bailey. 1980. Variation in bighorn sheep food habits as measured by fecal analysis. In Proceedings of the biennial symposium of the northern wild sheep and goat council, p. 29-41. Idaho Dep. Fish and Game. Salmon.
- Cowan, I. M. 1940. Distribution and variation in the native sheep of North America. Am. Midl. Nat. 24(3):505-580.
- Cowan, I. M. 1947. Range competition between mule deer, bighorn sheep, and elk in Jasper Park, Alberta. Trans. 12th North Am. Wildl. and Nat. Resour. Conf., p. 223-227. Wildl. Manage. Inst., Washington, D.C.
- Crump, W. 1971. The Wind River bighorn herd - a new approach to sheep habitat management. Trans. 1st North Am. Wild Sheep Conf., p. 174-181. E. Decker, ed. Colo. State Univ., Dep. Fish and Wildl. Biol., Fort Collins.
- Crump, W. I. 1957. Bighorn sheep reproduction and lamb survival study. Wyo. Game and Fish Dep. P-R Proj. Rep. W-27-R-10, 28 p. Cheyenne.
- Davis, John W., Lars H. Karstad, and Daniel O. Trainer (eds.) 1970. Infectious diseases of wild mammals. 421 p. Iowa State Univ. Press, Ames.
- Davis, John W., and Roy C. Anderson (eds.). 1971. Parasitic diseases of wild mammals. 364 p. Iowa State Univ. Press, Ames.
- Davis, W. B., and W. P. Taylor. 1939. The bighorn sheep of Texas. J. Mamm. 20(4):440-455.
- Dealy, E., D. A. Leckenby, and D. Concannon. 1981. Plant communities and their importance to wildlife. In Wildlife habitats in managed rangelands - the Great Basin of southeastern Oregon. USDA For. Serv. Gen. Tech. Rep. PNW-120, 66 p. Pac. Northwest Forest and Range Exp. Stn., Portland, Oreg.
- Dean, H. C. 1977. Desert bighorn sheep in Canyonlands National Park. M.S. thesis. Utah State Univ., Logan. 86 p.
- DeForge, J. R. 1972. Mans' invasion into the bighorns habitat. Trans. Desert Bighorn Counc. 16:112-115.
- Demarchi, D. A., and H. B. Mitchell. 1973. The Chilcotin River bighorn population. Can. Field-Nat. 87:433-454.
- Demarchi, R. A. 1965. An ecological study of the Ashnola bighorn winter ranges. M.S. thesis. Univ. British Columbia, Vancouver. 103 p.
- DeMartini, J. C., and R. B. Davies. 1976. *Muellerius capillaris* associated pneumonia in captive bighorn sheep. Trans. Northern Wild Sheep Counc., p. 117-124. Wyo. Game and Fish Dept., Cheyenne.
- DeMartini, J. C., and R. B. Davies. 1977. An epizootic of pneumonia in captive bighorn sheep infected with *Muellerius* sp. J. Wildl. Dis. 13:117-124.
- Denniston, A. 1965. Status of bighorn in the River Mountains of Lake Mead National Recreation Area. Trans. Desert Bighorn Counc. 9:27-34.
- Drewek, J., Jr. 1970. Population characteristics and behavior of introduced bighorn sheep in Owyhee County, Idaho. M.S. thesis. Univ. Idaho, Moscow. 46 p.
- Dunaway, D. J. 1971. Human disturbance as a limiting factor of Sierra Nevada bighorn sheep. Trans. 1st North Am. Wild Sheep Conf., p. 165-173. E. Decker, ed. Colo. State Univ., Dep. Fish and Wildl. Biol., Fort Collins.
- Dunaway, D. J. 1972. Winter food habits of California bighorn sheep in the Sierra Nevada. Trans. Desert Bighorn Counc. 16:21-29.
- Estes, R. D. 1979. Ecological aspects of bighorn sheep populations in southeastern Washington. M.S. thesis. Wash. State Univ., Pullman. 124 p.
- Fairaizl, S. D. 1978. Bighorn sheep in North Dakota: Population estimates, food habits, and their biogeochemistry. North Dakota Dep. Game and fish P-R Proj. Rep. W-67-R-17, 51 p. Bismarck.
- Ferrier, G. J. 1974. Bighorn sheep along the lower Colorado River, 1974-2050. Trans. Desert Bighorn Counc. 18:40-45.
- Foreyt, W. J., and D. A. Jessup. 1982. Fatal pneumonia of bighorn sheep following association with domestic sheep. J. Wildl. Dis. 18(2):163-168.
- Forrester, D. J. 1971. Bighorn sheep lungworm-pneumonia complex. In Parasitic diseases of wild animals, p. 158-173. J. W. Davis and R. C. Anderson, eds. Iowa State Univ. Press, Ames.
- Franklin, J. F., and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Frisina, M. R. 1974. Ecology of bighorn sheep in the Sun River Area of Montana during fall and spring. Mont. Fish and Game Dep. P-R Prog. Rep. W-120-R-4, 5, 68 p. Helena.

- Garrison, G. A., J. M. Skovlin, C. E. Poulton, and A. H. Winward.
1976. Northwest plant names and symbols for ecosystem inventory analysis. 4th ed. USDA For. Serv. Gen. Tech. Rep. PNW-46, 263 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Geist, V.
1971. Mountain sheep, a study in behavior and evolution. 383 p. Univ. Chicago Press, Chicago and London.
- Geist, V., and R. G. Petocz.
1977. Bighorn sheep in winter: Do rams maximize reproductive fitness by spatial and habitat segregation from ewes? Can. J. Zool. 55:1802-1810.
- Graf, W.
1980. Habitat protection and improvement. In The desert bighorn, its life history, ecology, and management, p. 310-319. G. Monson and L. Sumner, eds. Univ. Arizona Press, Tucson.
- Haas, W. L.
1979. Ecology of an introduced herd of Rocky Mountain bighorn sheep in south-central Wyoming. M.S. thesis. Colo. State Univ., Fort Collins. 343 p.
- Hailey, T. L.
1971. Bighorn bedding and lambing sites. Texas parks and Wildl. Dep. P-R Proj. Rep. W-67-D-15, 4 p. Austin.
- Hall, E. R., and K. R. Kelson.
1959. The mammals of North America. 1,083 p. Ronald Press, New York.
- Halloran, A. F., and O. V. Deming.
1958. Water development for desert bighorn sheep. J. Wildl. Manage. 22(1):1-9.
- Hansen, C. G.
1980. Habitat. In The desert bighorn, its life history, ecology, and management, p. 64-79. G. Monson and L. Sumner, eds. Univ. Arizona Press, Tucson.
- Hansen, M. C.
1982. Status and habitat preference of California bighorn sheep on Sheldon National Wildlife Refuge, Nevada. M.S. thesis. Oreg. State Univ., Corvallis. 47 p.
- Hebert, D. M.
1973. Altitudinal migration as a factor in the nutrition of bighorn sheep. Ph.D. thesis. Univ. British Columbia, Vancouver. 357 p.
- Helvie, J. B.
1971. Bighorns and fences. Trans. Desert Bighorn Coun. 15:53-62.
- Hibler, C. P.
1976. Investigation of spontaneous diseases of bighorn sheep. In P-R Prog. Rep. W-41-R-25/wk. pl. 1/Job No. 26, p. 75-114. Colo. Div. Wildl., Denver.
- Hibler, C. P.
1977. Investigation of spontaneous diseases of bighorn sheep. In P-R Prog. Rep. W-41-R-26/wk. pl. 1/Job No. 25, p. 93-110. Colo. Div. Wildl., Denver.
- Hibler, C. P., and T. R. Spraker.
1976. Treatment of bighorn sheep for lungworm. Trans. 2nd North Am. Wild Sheep Conf., p. 66-68. Colo. State Univ., Dep. Fish. and Wildl. Biol., Fort Collins.
- Hicks, L. L., and J. M. Elder.
1979. Human disturbance of Sierra Nevada bighorn sheep. J. Wildl. Manage. 43(4):909-915.
- Honess, R. F.
1942. Lungworms of domestic sheep and bighorn sheep in Wyoming. Univ. Wyo. Agric. Exp. Stn. Bull. No. 255, 25 p. Laramie.
- Honess, R. F., and N. M. Frost.
1942. A Wyoming bighorn sheep study. Wyoming Dep. Game and Fish Bull. No. 1, 127 p.
- Horejsi, B.
1976. Some thoughts and observations on harassment and bighorn sheep. In Proceedings of the northern wild sheep council, p. 149-155. Wyo. Fish and Game Dep., Cheyenne.
- Howard, V. W., Jr., and D. G. Lorenzo.
1975. Vegetation and food habits of Mexican bighorn sheep in the Game-Coin Enclosure near Red Rock. New Mexico State Univ. Agric. Exp. Stn. Rep. 303, 17 p. La Cruces.
- Howe, D. L., G. T. Woods, and G. Marquis.
1966. Infection of bighorn sheep (*Ovis canadensis*) with *Myxovirus parainfluenza - 3* and other respiratory viruses. Results of serologic tests and culture of nasal swabs and lung tissue. Bull. Wildl. Dis. Assoc. 2:34-37.
- Irvine, C. A.
1969. The desert bighorn sheep of southeastern Utah. Utah Div. Fish and Game Publ. No. 69-12, 99 p. Salt Lake City.
- Jahn, L. R., and J. B. Trefethan.
1978. Funding wildlife conservation programs. In Wildlife and America—contributions to an understanding of American Wildlife and its conservation, p. 456-470. H. P. Brokaw, ed. Counc. Environ. Qual., Washington, D.C.
- Jessup, D. A.
1980. Lava Beds bighorn sheep dieoff report as of 9/4/80. Calif. Dep. Fish and Game, Sacramento. 6p. typescript.
- Johnson, B. K., and D. R. Smith.
1980. Food habits and forage preferences of bighorn sheep in alpine and subalpine communities. In Proceedings of the biennial symposium of the northern wild sheep and goat council, p. 1-17. Idaho Dep. Fish and Game.
- Jones, F. L., G. Hittner, and R. Gard.
1957. Report on a survey of bighorn sheep in the Santa Rosa Mountains, Riverside County. Calif. Fish and Game 43(3):179-191.
- Jorgensen, M. C., and R. E. Turner, Jr.
1973. The desert bighorn sheep of Anza-Borrego Desert State Park. Trans. Desert Bighorn Coun. 17:81-88.

- Kistner, T. P., S. M. Matlock, D. Wyse, and G. E. Mason.  
 1977. Helminth parasites of bighorn sheep in Oregon. *J. Wildl. Dis.* 13(4):125-130.
- Koplin, J. R.  
 1960. New developments on water requirements on the desert game range. *Trans. Desert Bighorn Counc.* 4:54-57.
- Kornet, C. A.  
 1978. Status and habitat use of California bighorn sheep on Hart Mountain, Oregon. M.S. thesis. Oregon State Univ., Corvallis. 49 p.
- Lange, R.  
 1980. Part 2: The scabies mite. *New Mexico Wildl.* 25(1):8-12.
- Lange, R. E., A. B. Sandoval, and W. P. Meleney.  
 1980. Psoroptic scabies in bighorn sheep (*Ovis canadensis mexicana*) in New Mexico. *J. Wildl. Dis.* 16(1):77-82.
- Lauer, J. L., and J. M. Peek.  
 1976. Big game-livestock relationships on the bighorn sheep winter range, East Fork Salmon River, Idaho. *College of For., Wildl. and Range Sci. Bull.* No. 12, 44 p. Moscow, Idaho.
- Leslie, D. M., Jr., and C. L. Douglas.  
 1979. Desert bighorn sheep of the River Mountains, Nevada. *Wildl. Monogr.* No. 66, 56 p.
- Light, J. T.  
 1971. An ecological view of bighorn habitat on Mt. San Antonio. *Trans. 1st North Am. Wild Sheep Conf.*, p. 150-157. E. Decker, ed. Colo. State Univ., Dep. Fish and Wildl. Biol., Fort Collins.
- Light, J. T., F. A. Winter, and H. Graham.  
 1967. San Gabriel bighorn habitat management plan. Angeles and San Bernadino National Forests, San Bernadino, Calif. 32 p.
- Light, J. T., T. R. Zrelack, and H. Graham.  
 1966. San Gorgino bighorn habitat management plan. San Bernadino National Forest, San Bernadino, Calif. 24 p.
- Martin, S. C.  
 1978. Grazing systems - what can they accomplish? *Rangeman's J.* 5(1):14-16.
- Maser, C., J. M. Geist, D. M. Concannon, R. Anderson, and B. Lovell.  
 1979. Geomorphic and edaphic habitats. In *Wildlife habitats in managed rangelands - the Great Basin of southeastern Oregon*. USDA For. Serv. Gen. Tech. Rep. PNW-99, 84 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- McCann, L. J.  
 1956. Ecology of the mountain sheep. *Am. Midl. Nat.* 56(2):297-324.
- McCollough, S. A., A. Y. Cooperrider, and J. A. Bailey.  
 1980. Impact of cattle grazing on bighorn sheep habitat at Trickle Mountain, Colorado. In *Proceedings of the biennial symposium of the northern wild sheep and goat council*, p. 42-59. Idaho Dep. Fish and Game. Salmon.
- McCullough, D. R., and E. R. Schneegas.  
 1966. Winter observations of the Sierra Nevada bighorn sheep. *Calif. Fish and Game* 52(2):68-84.
- McCutchen, H. E.  
 1981. Desert bighorn zoogeography and adaptation in relation to historic land use. *Wildl. Soc. Bull.* 9(3):171-179.
- McKee, J. E., and H. W. Wolf (Eds.).  
 1963. Water quality criteria. *State Water Qual. Control. Board Publ.* No. 3-A, 548 p. Sacramento, Calif.
- McQuivey, R. P.  
 1978. The bighorn sheep of Nevada. *Nevada Dep. Fish and Game Biol. Bull.* No. 6, 81 p. Reno.
- Meehan, W. R., and W. S. Platts.  
 1978. Livestock grazing and the aquatic environment. *J. Soil and Water Conserv.* 33(6):274-278.
- Mensch, J. L.  
 1969. Desert bighorn (*Ovis canadensis nelsoni*) losses in a natural trap tank. *Calif. Fish and Game* 55(3):237-238.
- Moen, A. N.  
 1973. *Wildlife ecology*. 458 p. W. H. Freeman and Company, San Francisco.
- Morgan, J. K.  
 1968. Rocky Mountain bighorn sheep investigations. *Idaho Fish and Game Dep. P-R Proj. Rep. W-85-R-18/Job. No. 11*, 80 p. Boise.
- Morgan, J. K.  
 1969. Rocky Mountain bighorn sheep investigations. *Idaho Fish and Game Dep. P-R Proj. Rep. W-85-R-18/Job No. 11*, 73 p. Boise.
- Nelson, M.  
 1966. Problems of recreational use of game refuges. *Trans. Desert Bighorn Counc.* 10:13-20.
- Oleodemeyer, J. L., W. J. Barmore, and D. L. Gilbert.  
 1971. Winter ecology of bighorn sheep in Yellowstone National Park. *J. Wildl. Manage.* 35(2):257-269.
- Packard, F. M.  
 1946. An ecological study of the bighorn sheep in Rocky Mountain National Park, Colorado. *J. Mamm.* 27(1):3-28.
- Parks, J. B., G. Post, T. Thorne, and P. Nash.  
 1972. Parainfluenza - 3 virus infection in Rocky Mountain bighorn sheep. *J. Am. Vet. Med. Assoc.* 161(6):669-672.
- Peek, J. M., R. A. Riggs, and J. L. Lauer.  
 1979. Evaluation of fall burning on bighorn sheep winter range. *J. Range manage.* 32(6):430-432.
- Pitt, M. D., and B. M. Wikeem.  
 1978. Diet preference of California bighorn sheep on native rangeland in south-central British Columbia. In *Proceedings of the 1978 northern wild sheep and goat conference*, p. 331-349. British Columbia Fish and Wildl. Branch. Penticton.
- Riggs, R. A.  
 1977. Winter habitat use patterns and populations of bighorn sheep in Glacier National park. M.S. thesis. Univ. Idaho, Moscow. 85 p.

- Risenhoover, K. L., and J. A. Bailey.  
 1980. Visibility an important factor for an indigenous, low-elevation bighorn herd in Colorado. In Proceedings of the biennial symposium of the northern wild sheep and goat council, p. 18-28. Idaho Dep. Fish and Game.
- Robinson, C. S., and F. P. Cronemiller.  
 1954. Notes on the habitat of the desert bighorn in the San Gabriel Mountains of California. Calif. Fish and Game 40:267-271.
- Robinson, R. M., T. L. Hailey, C. W. Livingston, and J. W. Thomas. 1967. Bluetongue in the desert bighorn sheep. J. Wildl. Manage. 31(1):165-168.
- Russo, J. P.  
 1956. The desert bighorn sheep in Arizona. Ariz. Game and Fish Dep. Bull. No. 1, 153 p. Tucson.
- Rutherford, W. H.  
 1972. Status of transplanted bighorn sheep in Colorado. Colo. Div. Game, Fish and Parks Game Inf. Leafl. No. 92, 3 p.
- Samuel, W. M., G. A. Chalmers, J. G. Stelfox, A. Loewen, and J. J. Thomsen.  
 1975. Contagious ecthyma in bighorn sheep and mountain goat in western Canada. J. Wildl. Dis. 11(1):26-31.
- Samuel, W. M., W. K. Hall, J. G. Stelfox, and W. D. Wishart.  
 1978. Parasites of mountain goat, *Oreamnos americanus* (Blainville), of west central Alberta with a comparison of the helminths of mountain goat and Rocky Mountain bighorn sheep, *Ovis c. canadensis* Shaw. In Proceedings of the first international mountain goat symposium, p. 212-225. Kalispell, Mont.
- Schallenger, A.  
 1965. Big game forage competition in Sun River Canyon. M.S. thesis. Mont. State Univ., Bozeman. 44 p.
- Seton, E. T.  
 1929. The lives of game animals. vol. 3, part 2. 780 p. Doubleday, Doran, and Co., Garden City, NY.
- Shannon, N. H., R. J. Hudson, V. C. Brink, and W. D. Kitts.  
 1975. Determinants of spatial distribution of Rocky Mountain bighorn sheep. J. Wildl. Manage. 39(2):387-401.
- Skovlin, J. M.  
 1965. Improving cattle distribution of western mountain rangelands. U.S. Dep. Agric. Farmers Bull. No. 2212, 14 p. Washington, D.C.
- Smith, D. R.  
 1954. The bighorn sheep in Idaho, its status, life history, and management. Idaho Dep. Fish and Game Wildl. Bull. No. 1, 154 p. Boise.
- Spalding, D. J., and J. N. Bone.  
 1969. The California bighorn sheep of the south Okanagan Valley, British Columbia. British Columbia Fish and Wildl. Branch, Wildl. Manage. Publ. No. 3, 45 p. Vancouver.
- Spalding, D. J., and H. B. Mitchell.  
 1970. Abundance and distribution of California bighorn sheep in North America. J. Wildl. Manage. 34(2):473-475.
- Stelfox, J. G.  
 1971. Bighorn sheep in the Canadian Rockies: a history 1800-1970. Can. Field-Nat. 85(2):101-122.
- Stelfox, J. G.  
 1976. Range ecology of Rocky Mountain bighorn sheep in Canadian national parks. Ca. Wildl. Serv. Rep. Ser. No. 39, 50 p.
- Stoddart, L. A., A. D. Smith, and T. W. Box.  
 1975. Range management. 532 p. McGraw-Hill Book Co., New York.
- Sugden, L. G.  
 1961. The California bighorn in British Columbia with particular reference to the Churn Creek herd. British Columbia Dep. Recreation and Conserv. 58 p. Victoria.
- Thomas, J. W., R. J. Miller, H. Black, J. E. Rodiek, and C. Maser.  
 1976. Guidelines for maintaining and enhancing wildlife habitat in forest management in the Blue Mountains of Oregon and Washington. Trans. 41st North Am. Wildl. and Nat. Resour. Conf., p. 452-476.
- Thorne, E. T., T. Varcalli, K. Becker, and G. B. Butler.  
 1978. Some thoughts on the consequences of non-trophy sheep hunting in the Wind River Mountains of Wyoming. In Proceedings of the 1978 northern wild sheep and goat conference, p. 42-51. British Columbia Fish and Wildl. Branch. Penticton.
- Todd, J. W.  
 1972. A literature review on bighorn sheep food habits. Colo. Div. Game, Fish, and Parks Spec. Rep. No. 27, 21 p. Denver.
- Trainer, D. O.  
 1970. Bluetongue. In Infectious diseases of wild mammals, p. 55-59. J. W. Davis, L. H. Karstad, and D. O. Trainer, eds. Iowa State Univ. Press, Ames.
- Trefethan, J. B. (Ed).  
 1975. The wild sheep in modern North America. 302 p. Winchester Press, New York.
- Turner, J. C., Jr.  
 1973. Water, energy and electrolyte balance in the desert bighorn sheep, *Ovis canadensis*. Ph.D. thesis. Univ. Calif., Riverside. 138 p.
- Turner, J. C., and R. A. Weaver.  
 1980. Water. In The desert bighorn, its life history, ecology, and management, p. 100-112. G. Monson and L. Sumner, eds. Univ. Arizona Press, Tucson.
- Uhazy, L. S., and J. C. Holmes.  
 1970. Helminths of the Rocky Mountain bighorn sheep in western Canada. Can. J. Zool. 49:507-512.

- Uhazy, L. S., J. L. Mahrt, and J. C. Holmes.  
 1971. Coccidia of Rocky Mountain bighorn sheep in western Canada. *Can. J. Zool.* 49:1461-1464.
- Van Dyke, W. A.  
 1978. Population characteristics and habitat utilization of bighorn sheep, Steens Mountain, Oregon. M.S. thesis. Oreg. State Univ., Corvallis. 87 p.
- Wagner, F. H.  
 1978. Livestock grazing and the livestock industry. In *Wildlife and America – contributions to an understanding of American wildlife and its conservation*, p. 121-145. H. R. Brokaw, ed. Counc. Environ. Qual., Washington, D.C.
- Weaver, R. A.  
 1972. California bighorn in the Sierra Nevada Mountain Range. Calif. Dep. Fish and Game Wildl. Manage. Adm. Rep. No. 72-7, 17 p.
- Wehausen, J. D.  
 1980. Sierra Nevada bighorn sheep: history and population ecology. Ph.D. diss. Univ. Michigan, Ann Arbor. 240 p.
- Welles, R. E., and F. B. Welles.  
 1961. The bighorn of Death Valley. *Natl. Parks Fauna Ser.* No. 6, 242 p. U.S. Gov. Print. Off., Washington, D.C.
- Welsh, G. W.  
 1971. What's happening to our sheep? *Trans. Desert Bighorn Counc.* 15:63-68.
- Williams, J.  
 1980. Desert rescue. *New Mexico Wildl.* 25(2):2-5, 25-29.
- Williams, J.  
 1981. A success story. *New Mexico Wildl.* 26(2): 2-5.
- Wilson, L. O.  
 1968. Distribution and ecology of the desert bighorn in southeast Utah. Utah Div. Fish and Game Publ. 68-5, 220 p. Salt Lake City.
- Wilson, L. O.  
 1977. Guidelines and recommendations for design and modification of livestock watering developments to facilitate safe use by wildlife. U.S. Dep. Inter. Bur. Land Manage. Tech. Note 305, 20 p. Boise, Idaho.
- Woodgerd, W.  
 1964. Population dynamics of bighorn sheep in Wildhorse Island. *J. Wildl. Manage.* 28(2):381-391.
- Woolf, A.  
 1968. Summer ecology of bighorn sheep in Yellowstone National Park. M.S. thesis. Colo. State Univ., Fort Collins. 112 p.
- Woolf, A., and D. C. Kradel.  
 1973. Mortality in captive bighorn sheep – clinical, hematological, and pathological observations. *J. Wildl. Dis.* 9:12-17.
- Yoakum, J.  
 1971. Habitat management for the desert bighorn. *Trans. 1st North Am. Wild Sheep Conf.*, p. 158-164. E. Decker, ed. Colo. State Univ., Dep. Fish and Wildl. Biol., Fort Collins.
- Yoakum, J.  
 1973. Survey of potential bighorn habitat on National resource land in the Southwest. *Trans. Desert Bighorn Counc.* 17:123-136.
- Yoakum, J. D.  
 1964. Bighorn food habit-range relationships in the Silver Peak Range, Nevada. *Trans. Desert Bighorn counc.* 8:95-102.
- Yoakum, J. D.  
 1966. Comparison of mule deer and desert bighorn seasonal food habits. *Trans. Desert Bighorn Counc.* 10:65-70.
- Yoakum, J., W. P. Dasmann, H. R. Sanderson, C. M. Nixon, and H. S. Crawford.  
 1980. Habitat improvement techniques. In *Wildlife management techniques manual*, p. 329-404. S. D. Schemnitz, ed. Wildl. Soc., Washington, D.C.

## Appendix

### Common and Scientific Names<sup>1</sup>

Common name	Scientific name
<b>MAMMALS</b>	
Bighorn sheep	<i>Ovis canadensis</i>
California bighorn sheep	<i>Ovis canadensis californiana</i>
Cougar	<i>Felis concolor</i>
Coyote	<i>Canis latrans</i>
Deer	<i>Odocoileus</i> spp.
Desert bighorn sheep	<i>Ovis canadensis nelsoni</i>
Domestic cow	<i>Bos taurus</i>
Domestic goat	<i>Capra hircus</i>
Domestic sheep	<i>Ovis aries</i>
Horse	<i>Equus caballus</i>
North American elk	<i>Cervus elaphus</i>
Pronghorn	<i>Antilocapra americana</i>
Rocky Mountain bighorn sheep	<i>Ovis canadensis canadensis</i>
<b>BIRDS</b>	
Golden eagle	<i>Aquila chrysaetos</i>
<b>PLANTS</b>	
Antelope bitterbrush	<i>Purshia tridentata</i>
Arrowleaf balsamroot	<i>Balsamorhiza sagittata</i>
Aspen	<i>Populus</i> spp.
Basin big sagebrush	<i>Artemisia tridentata</i>
Bearded bluebunch wheatgrass	<i>Agropyron spicatum</i>
Big sagebrush	<i>Artemisia tridentata</i>
Black greasewood	<i>Sarcobatus vermiculatus</i>
Black sagebrush	<i>Artemisia nova</i>
Blue elderberry	<i>Sambucus cerulea</i>
Bluegrasses	<i>Poa</i> spp.
Bolander silver sagebrush	<i>Artemisia cana bolanderi</i>
Bottlebrush squirreltail	<i>Sitanion hystrix</i>
Bud sagebrush	<i>Artemisia spinescens</i>
Cheatgrass brome	<i>Bromus tectorum</i>
Cherry	<i>Prunus</i> spp.
Chokecherry	<i>Prunus virginiana</i>
Cinquefoil	<i>Potentilla</i> <i>fruticosa</i>
Cleftleaf sagebrush	<i>Artemisia arbuscula thermopola</i>
Cobre rockcress	<i>Arabis cobrensis</i>
Common snowberry	<i>Symphoricarpu</i> s <i>albus</i>
Common winterfat	<i>Eurotia lanata</i>
Cottonwood	<i>Populus</i> spp.
Creambush rockspirea	<i>Holodiscus discolor</i>
Curlleaf mountain-mahogany	<i>Cercocarpus ledifolius ledifolius</i>

<sup>1</sup> Mammal names from Chapman and Feldhamer (1982); bird names from American Ornithologist's Union (1957); plant names from Garrison et al. (1976); parasite and disease names from Davis et. al. (1970).

## Appendix (continued)

Common name	Scientific name
Currant	<i>Ribes</i> spp.
Cushion buckwheat	<i>Eriogonum ovalifolium</i>
Douglas-fir	<i>Pseudotsuga menziesii</i>
Early low sagebrush	<i>Artemisia longiloba</i>
Erigeron	<i>Erigeron</i> spp.
Fairway crested wheatgrass	<i>Agropyron cristatum</i>
Fir	<i>Abies</i> spp.
Fourwing saltbush	<i>Atriplex canescens</i>
Giant wildrye	<i>Elymus cinereus</i>
Idaho fescue	<i>Festuca idahoensis</i>
Indian ricegrass	<i>Oryzopsis hymenoides</i>
Juniper	<i>Juniperus</i> spp.
Lomatium	<i>Lomatium</i> spp.
Low sagebrush	<i>Artemisia arbuscula arbuscula</i>
Lupine	<i>Lupinus</i> spp.
Mallow ninebark	<i>Physocarpus malvaceus</i>
Meadow barley	<i>Hordeum brachyantherum</i>
Milkvetch	<i>Astragalus</i> spp.
Mountain big sagebrush	<i>Artemisia tridentata vaseyana</i>
Mountain-mahogany	<i>Cercocarpus</i> spp.
Mountain silver sagebrush	<i>Artemisia cana sub. viscidula</i>
Mountain snowberry	<i>Symporicarpus oreophilus</i>
Penstemon	<i>Penstemon</i> spp.
Phlox	<i>Phlox</i> spp.
Pine	<i>Pinus</i> spp.
Pinegrass	<i>Calamagrostis rubescens</i>
Pinnate tansymustard	<i>Descurainia pinnata</i>
Prairie junegrass	<i>Koeleria cristata</i>
Quaking aspen	<i>Populus tremuloides</i>
Rabbitbrush	<i>Chrysothamnus</i> spp.
Rose	<i>Rosa</i> spp.
Sagebrush	<i>Artemisia</i> spp.
Saskatoon serviceberry	<i>Amelanchier alnifolia</i>
Sedge	<i>Carex</i> spp.
Shadscale saltbush	<i>Atriplex confertifolia</i>
Shinyleaf spiraea	<i>Spiraea lucida</i>
Spiny hopsage	<i>Atriplex spinosa</i>
Squaw apple	<i>Peraphyllum ramosissimum</i>
Subalpine big sagebrush	<i>Artemisia tridentata form spiciformis</i>
Threetip sagebrush	<i>Artemisia tripartata</i>
Thurber's needlegrass	<i>Stipa thurberiana</i>
Wallflower phoenicaulis	<i>Phoenicaulis cheiranthoides</i>
Western juniper	<i>Juniperus occidentalis</i>
Wild buckwheat	<i>Eriogonum</i> spp.
Willow	<i>Salix</i> spp.
Wyoming big sagebrush	<i>Artemisia tridentata wyomingensis</i>
Yarrow	<i>Achillea millefolium</i>

## **Appendix (continued)**

<b>Common name</b>	<b>Scientific name</b>
<b>PARASITES AND DISEASES</b>	
Bacteria	<i>Corynebacterium pogenes</i>
	<i>Pasteurella multocida</i>
Lungworms	<i>Muelleruis</i> sp.
	<i>Protostrongylus stilesi</i>
	<i>Protostrongylus rushi</i>
Nematodes	<i>Nematodirus</i> spp.
<b>INSECTS</b>	
Scab mite	<i>Psoroptes ovis</i>
Sheep bot fly	<i>Oestrus ovis</i>



**WILDLIFE HABITATS IN MANAGED RANGELANDS—THE  
GREAT BASIN OF SOUTHEASTERN OREGON**

**Technical Editors**

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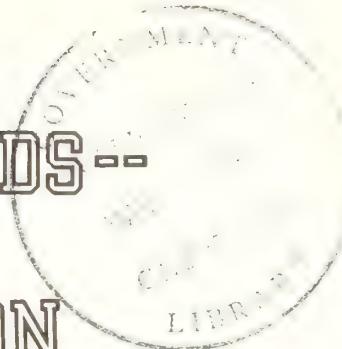
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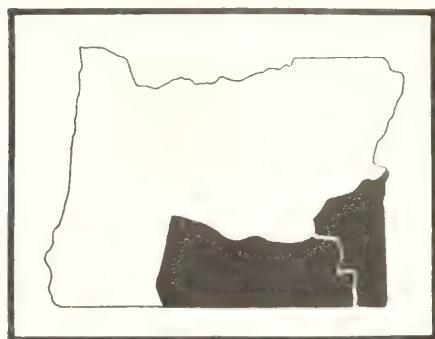
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WILDLIFE HABITATS  
IN MANAGED RANGELANDS --  
THE GREAT BASIN OF  
SOUTHEASTERN OREGON



## INTRODUCTION

CHRIS MASER  
JACK WARD THOMAS



## **ABSTRACT**

The need for a way by which rangeland managers can account for wildlife in land-use planning, in on-the-ground management actions, and in preparation of environmental impact statements is discussed. Principles of range-land-wildlife interactions and management are described along with management systems. The Great Basin of southeastern Oregon was selected as a well-defined area for which to develop and display the rangeland-wildlife management principles. This paper introduces the 14-chapter series and outlines each briefly.

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This publication is part of the series **Wildlife Habitats in Managed Rangelands—The Great Basin of Southeastern Oregon**. The series on rangelands is adapted from “Wildlife Habitats in Managed Forests—the Blue Mountains of Oregon and Washington” (Thomas 1979), and though parts of the series on rangelands resemble those on the forest, others are completely new. The series provides range managers with information on wildlife and its relationship to habitat conditions in managed rangelands.

The setting for this series of papers is the Great Basin of southeastern Oregon—the Basin and Range and Owyhee Upland Provinces of Franklin and Dyrness (1973) (fig. 1). The information is specific to the Great Basin of southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands.

The series includes 14 separate publications. Although each part is an independent treatment of a specific subject, when combined in the sequence in which they appear on the inside back cover, the individual parts will be as chapters in a book.

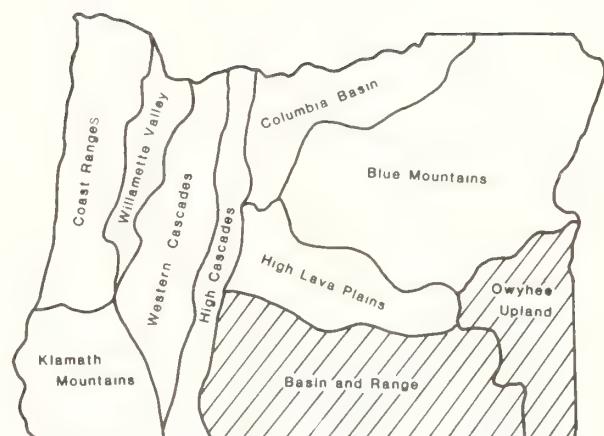


Figure 1.—The physiographic and geological provinces of Oregon (after Franklin and Dyrness 1973). The shaded portion is the area referred to in this report as the “Great Basin of southeastern Oregon.”

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## Introduction

Until a few years ago, a rangeland manager's only concern with wildlife was with "predators" and "big game." The law neither recognized nor required an accountability for wildlife. But times, laws, public demands, and politics have changed. Public rangelands are now considered a prime supplier of livestock and recreation. In fact, they are becoming ever more intensively managed to meet the Nation's burgeoning demands for minerals, water, recreation, grazing, and wildlife. Rangeland managers are under increasing pressure to account for wildlife in management activities, particularly land-use planning. And wildlife means all species—not just species that are hunted, or are esthetically pleasing, or are classified as threatened or endangered. Specific responsibilities for protection and enhancement of wildlife habitats on managed rangelands have been set forth by Federal laws and other legislation. This series of publications is designed to help managers deal more effectively with these new responsibilities.

In turn, the managers are asking more and tougher questions about how range management practices will affect wildlife. The response of wildlife biologists too often varies from "Don't do it" to "We don't know enough to give you an answer." Neither response helps a manager make the necessary evaluations and decisions, and to do nothing is seldom a realistic alternative—economically, politically, or biologically.

Although we probably will never have enough knowledge to make a perfect analysis of the impacts of rangeland management action on wildlife habitat, more information is available than has been used. To be useful, however, it must be organized to make sense biologically and in terms of livestock management.

Past wildlife management in rangelands has been considered from a limited viewpoint in that single species or small numbers of species have been studied and planned for. As a result, wildlife biologists and range specialists have been able to effectively evaluate the impacts of management on only a few species of wildlife.

Perhaps the greatest challenge to professionals engaged in range research and management is to organize knowledge and insights into analytical tools and management strategies that can be readily applied. We began by asking a simple question. What do rangeland managers do that affects wildlife? They manage habitat. Every decision a manager makes that changes the landscape alters wildlife habitat. Habitat is an entity that can be qualified and quantified and for which a manager can be held accountable. And because maintenance of appropriate habitat is the foundation of all wildlife management, it is the key to organizing the knowledge about wildlife so it can be used in managing rangelands. We provide a framework for planning that uses habitat as the key to managing wildlife and thereby makes managers accountable for their actions.

The information presented is a reasonable facsimile of the way managed rangelands and wildlife interrelate. The series may be considered a working hypothesis. It is a place to start—a way to derive responses to questions for which there are no certain answers. As Taylor (1956, p. xi) said: "no . . . book dealing with living creatures is in any sense final. The subject . . . is so fascinatingly complicated that no contribution can be . . . more than a progress report."

Much of the Nation's vast rangelands have changed dramatically in the last 200 years. They can no longer be considered wild because they are now managed to produce multiple benefits, dominated by livestock production but including wildlife. Private lands, of course, are managed to meet the owner's objective—usually production of livestock. Management to enhance livestock production alters wildlife habitat more than any other range management activity.

This series has three purposes: (1) to develop a common understanding of wildlife habitats on managed rangelands; (2) to provide a system for predicting the impacts of range management practices on wildlife; and (3) to show how the system can be applied to a specific area—in this case, the Great Basin in southeastern Oregon.

With the information provided, resource specialists can work together to assure the continued existence of most, if not all, wildlife habitats in managed rangelands.

Livestock management and wildlife habitat management are compatible on public rangelands, but only if the needs of wildlife are recognized and accounted for along with the needs of livestock. Their compatibility can be realized through a better understanding of plant and animal communities, how they change over time, and how they respond to livestock grazing and vegetative manipulation.

By long-standing agreement, the manipulation of nonmigratory wildlife populations or regulation of the harvest of such wildlife on federally managed land is the prerogative of the States. Habitat management on public land is the responsibility of the agencies assigned to manage federally owned lands. Close cooperation is therefore required in setting and achieving wildlife management goals because management of wildlife on public lands is the joint responsibility of both State and Federal governments.

## **Wildlife as a Product of Rangeland Management**

Management of rangelands is the process of controlling the environment to produce a mix of desired products. That mix changes with time, economic conditions, and capability of the land. Congress, through laws, determines what these products, including wildlife, on public lands shall be (fig. 2). The "granddaddy" law of public rangelands was the 1934 Taylor Grazing Act, which directed the Secretary of the Interior to preserve wildlife (Bean 1977). A number of laws (fig. 2) specify or intimate that wildlife shall be a product of Federal lands and that wildlife shall be considered in every management decision. Other regulations result from agency and court interpretations of these laws. Managers of State lands and private landowners are influenced by applicable State laws.

Wildlife habitat, on most managed rangelands, has been a byproduct of management to enhance production of livestock. As demands have grown for the products of rangelands, it has become obvious that such clichés as "good range management is good wildlife management" will no longer suffice. Passage of the National Environmental Policy Act of 1969 (U.S. Laws, Statutes, etc.; Public Law 91-190) required that the environmental effects and trade-offs of any federally financed project must be fully evaluated.

## **The Need**

How is a public rangeland manager to balance demands for rangelands, including wildlife, and still maintain a sustained yield of livestock forage? How can managers account for the needs of all wildlife? In seeking answers to these questions, the wisdom of two of Commoner's (1971) "laws" of ecology becomes apparent—"everything is connected to everything else," and "there is no such thing as a free lunch." Any action that alters vegetation has an influence on wildlife habitat and, in turn, on wildlife. If wildlife is of concern, goals for wildlife must be established and all management actions must be judged against those goals. Rangeland managers must not be solely livestock managers. They must take a more holistic view.

The Federal Land Policy and Management Act of 1976 (U.S. Laws, Statutes, etc.; Public Law 90-2743) requires that detailed and holistic plans be prepared for the management of public rangelands. Further, the National Environmental Policy Act of 1969 (U.S. Laws, Statutes, etc.; Public Law 91-190) requires that the environmental impacts and consequences of planned actions involving Federal funds be examined and revealed. One of the weakest aspects of such planning has been the inability of managers to predict the effects of management alternatives on wildlife populations. This has frequently resulted in criticism of land-use plans and environmental impact statements by the public, other agencies, and the courts.

Public Law No.

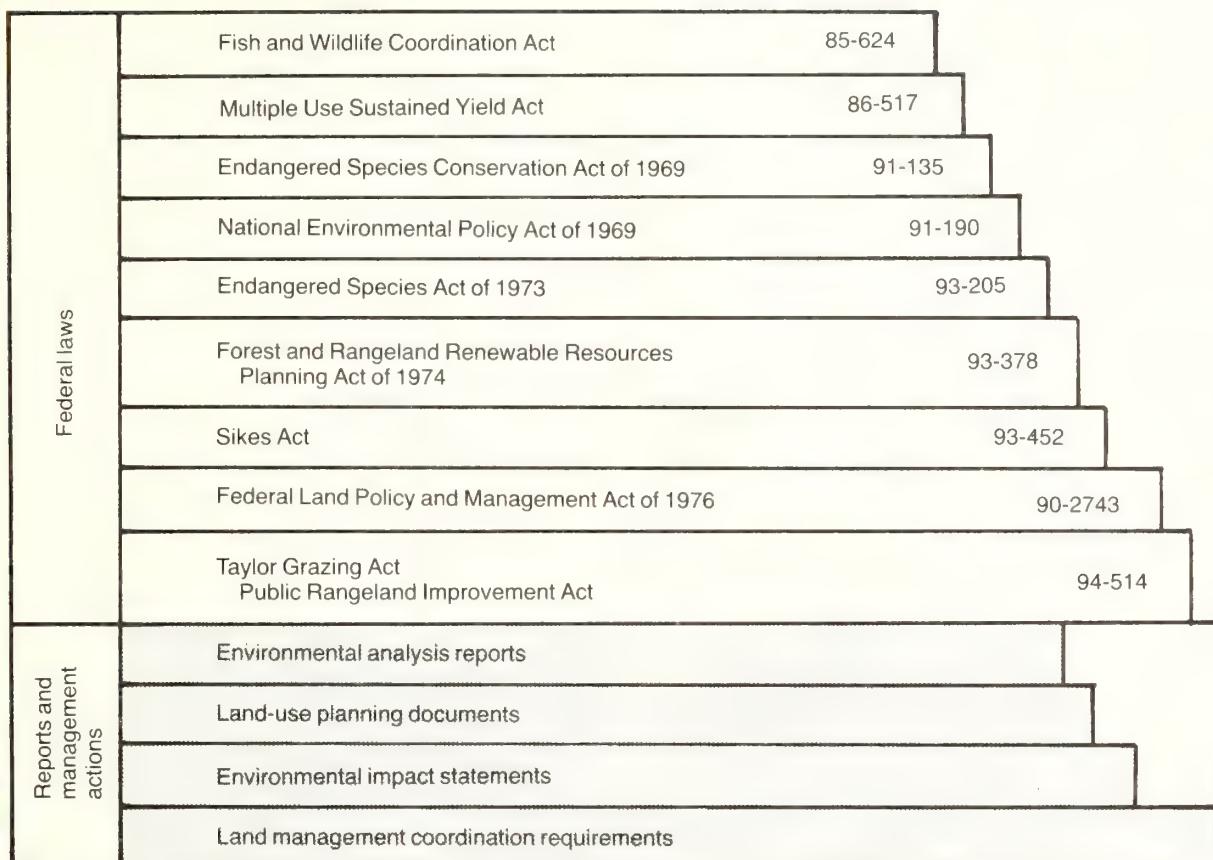


Figure 2.—Some major Federal laws and planning requirements that influence wildlife habitat management on public lands (adapted from Thomas 1979).

General criticism of rangeland management and land-use planning by conservationists and wildlife biologists does little to help wildlife. What will help are better techniques to predict the consequences of management on wildlife, whether good or bad. Managers need a conceptual framework that will enable them to: (1) account for habitat needs of all vertebrate wildlife, (2) emphasize management of particular wildlife species, and (3) identify habitats that require special attention. The greatest challenge is to integrate existing information so

it can be readily used in resource planning. Giles (1962, p. 404-405) described the problem as follows:

Certainly, research is needed, but while waiting, we need to work with what we have. Work to be done is not for the research staff, but the management team who sees the needs, recognizes limitations, and can make modifications to fit existing conditions. The "applied ecologist" needs to start applying.

Development of a process to consider the impacts of management on wildlife is needed. Land-use planning continues at full speed; large-scale conversions of sagebrush-dominated rangelands to crested wheatgrass and other species are being contemplated and implemented; and the demand for increased forage production (that is, increased livestock grazing) from public lands is incessant. Some say it is too soon to undertake such a task, that there is too little "hard" data. But there are really only two choices—too soon or too late. The first is preferable. With intensified management of rangelands, impacts on wildlife are magnified. We need to get on with the job.

Managers need more flexibility in applying technical information to local situations. The information is presented as a system to predict the consequences of management alternatives on wildlife, rather than as specific guidelines. Thus, a manager has the ability to respond to particular situations while being fully accountable for the impacts of such decisions on wildlife habitat. Managers can survey alternatives, make trade-offs, and account for those decisions.

## A Basic Assumption

A basic assumption about wildlife habitat in rangelands managed for multiple use is that management must be carried out in coordination with livestock management. On public rangelands in the Great Basin of southeastern Oregon, as in many other parts of North America, livestock production is the dominant land use. Large-scale alterations of wildlife habitat usually result from the manipulation of vegetation primarily to enhance livestock production. Management for livestock production, therefore, is de facto wildlife management. The degree to which it is good wildlife management depends on how well habitat is manipulated to achieve wildlife goals. These interrelationships are shown in figure 3.

Large-scale wildlife goals must be accomplished through rangeland management

because

management for enhanced livestock production:

- affects many acres
- is relatively well financed
- dramatically affects wildlife habitat
- has great impact on wildlife

whereas

management for wildlife habitat:

- affects relatively few acres (however, the acres affected are generally in "key" areas)
- has relatively little financing
- has relatively small influence on wildlife habitat (but does influence key habitat components in localized areas)
- has relatively small impact on wildlife (but could do much more with better financing)

Figure 3.—Large-scale management of wildlife habitat must be mainly accomplished through rangeland management (adapted from Thomas 1979).

Wildlife habitat management may require control of vegetation, but this is usually too expensive solely for wildlife purposes. There are exceptions, however, such as the establishment of special watering sources and protection of particular habitats from livestock grazing. Management practices undertaken to enhance livestock production can cause dramatic changes in wildlife habitat; these practices, when correctly planned and executed, can be a practical way to achieve wildlife habitat goals.

A wildlife biologist is normally responsible for making the manager aware of the ramifications of proposed management activities on wildlife habitats. A manager normally considers advice from many staff specialists and selects a course of action. But it is the field range specialist who actually manipulates the vegetation and alters habitat. It is therefore essential that range managers, range specialists, and wildlife biologists work closely together.

To paraphrase Giles (1962, p. 406), it is time to concede that the production of livestock has more intense, widespread influence on wildlife than any technique applied by a wildlife biologist to enhance habitat. In one large-scale manipulation of vegetation to enhance forage production for livestock, a rangeland manager can influence more habitat over a longer time than a wildlife manager, acting alone with current levels of funding, can create in a decade. Wildlife biologists, to be really effective, must simultaneously realize the potential of these rangeland manipulations to enhance forage for livestock and must increase their effectiveness in obtaining modifications in these practices to make them the least damaging, or even to enhance wildlife habitat.

## Principles of Rangeland-Wildlife Management

Resource management professionals come from varied backgrounds: range management, ecology, geology, wildlife biology, fisheries biology, engineering, animal husbandry, and landscape architecture, to name a few. To work together, they need a common vocabulary and understanding of range management principles, plant and animal ecology, and wildlife management. The relationship between terms used in range and wildlife habitat management is shown in figure 4. Touched on by Odum (1963), Leopold (1933), and Hylander (1966), these definitions are mainly from Thomas (1979).

**Habitat** is the place where an animal finds the required arrangement of food, cover, and water to meet its biological needs. Each species is adapted to a **habitat niche** or specific arrangement and amount of food, cover, and water. The role a particular wildlife species plays in the environment is referred to as its **ecological niche**.

A **plant community type** is a unique combination of plants that occurs in particular locations under certain environmental influences. The plant community type reflects the environmental influences of the site, such as soil, temperature, elevation, solar radiation, slope, aspect, and rainfall as they influence vegetation (Daubenmire 1976).

**Plant communities**, as described in chapter 2 (Dealy et al. 1981), are defined in terms of dominant overstory and understory species of climax vegetation. Several plant community types may be included. A plant community evolves through a general series of conditions as it progresses from bare ground to climax stage. This process is called **succession**, and the various stages are known as **successional stages**. But in rangeland communities in which the vegetation is manipulated, singly or in combination, by fire, mechanical means, herbicides, and ungulate grazing, succession is commonly so radically modified that when a relatively stable state is maintained by people or their domestic animals it can be called a stage of **disclimax** (= disturbance climax) or **anthrogenic subclimax** (= human generated) (Odum 1971). In this series, these disclimax states are referred to as **structural conditions**.

Each combination of a plant community and a successional stage or structural condition produces a unique set of habitat niches. The wildlife supported by these habitat niches make up the attendant **animal community**. The animals fill various ecological niches and, in turn, influence the plant community. Individual species may use a particular habitat on a seasonal or a yearlong basis. See also reviews of Meslow and Wight (1975) and Thomas et al. (1975).

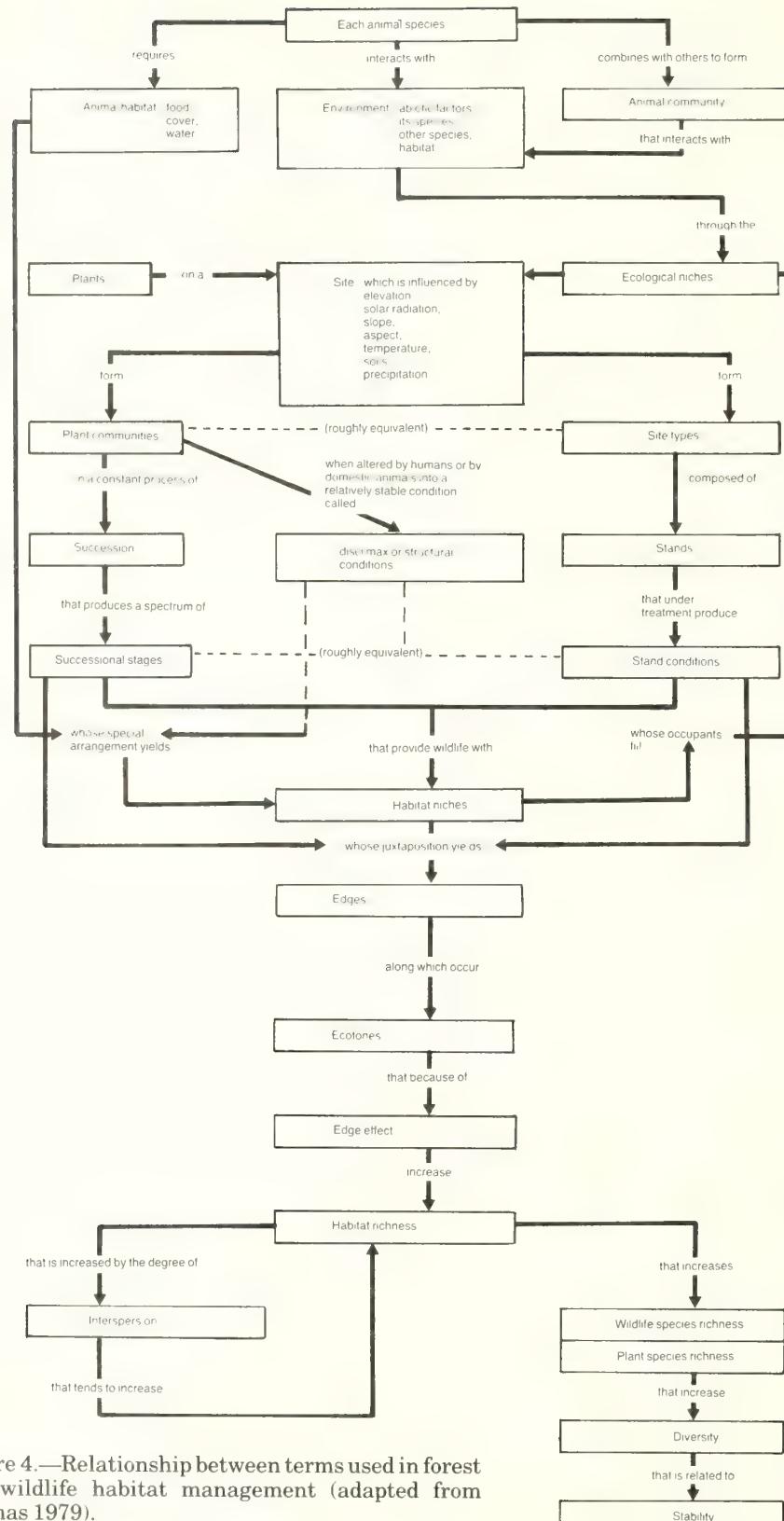


Figure 4.—Relationship between terms used in forest and wildlife habitat management (adapted from Thomas 1979).

Some of the terms already discussed have counterparts that are used primarily in range management. It is important to understand their relationship to the language of ecology and wildlife biology.

A **site** is an area considered in terms of its environment, particularly as this determines the type and quality of the vegetation the area can support. Sites are qualitatively classified into **site types** by their climate, soil, and vegetation. Site type is roughly analogous to the plant community.

Each site is occupied by one or more **stands**. A **stand** is a plant community that has sufficient uniformity of composition, size, density, age, spatial arrangement, and condition to distinguish it from adjacent communities. Stands are the common basis on which prescriptions to manipulate vegetation are considered. The **stand condition** can be described by measuring these factors. Manipulation of vegetation alters stand condition. When wildlife habitat is considered, stand condition is roughly analogous to successional stage or structural condition because both reflect the composition and structure of the stand.

The juxtaposition of plant communities, successional stages, or stand conditions within communities produces **edge**. The area where communities or successional stages overlap or produce a distinct combination of plants or structure is called the **ecotone**. Edges and their ecotones are rich habitat for wildlife because they have attributes of the edge itself plus those of the adjoining communities or successional stages (Leopold 1933). The influence of this phenomenon on animal populations is called **edge effect**.

Increasing the amount of edge increases **habitat richness**, which is a measure of the number of wildlife species resident within an area. **Interspersion** is a measure of the degree to which plant communities or successional stages mix. An increase in interspersion increases the amount of edge. In turn, this may increase **diversity** or the variety that exists in plant and animal communities (Patton 1975). Increased diversity in plant communities provides an increasing number of habitat niches

that, in turn, support more animal species. A rangeland with a high degree of diversity of communities and successional stages provides habitat for a wide variety of wildlife (Odum 1971).

Increased diversity is thought to be related to **community stability**. Stability is the ability of a community to withstand catastrophe (Margalef 1969) or to return it to its original state after severe alteration. Diversity is assumed to provide flexibility to managers by insuring resilience to recover from disturbance to the "system." Such a cause and effect is suspected but has not been proved. Odum (1971, p. 256) stated:

If it can be shown that biotic diversity does indeed enhance physical stability in the ecosystem, or is the result of it, then we would have an important guide for conservation practice. . . . is variety only the spice of life or is it a necessity for the long life of the total ecosystem comprising man and nature?

A **rangeland ecosystem** is a dynamic complex of plant and animal communities, along with the abiotic environment that comprises one functioning whole. Any change in vegetative structure or composition will favor some wildlife species while adversely affecting others. Such changes can affect the number and type of wildlife species and their use of habitat.

## Rangeland-Wildlife Management Systems

Wildlife management is the scientifically based art of skillfully controlling habitat to enhance conditions for a selected species or of manipulating animal populations to achieve other desired ends (fig. 5). The term "wildlife management" implies the ability and managerial flexibility to control habitat factors or animal populations, or both (Giles 1971, Leopold 1933, Trippensee 1948).

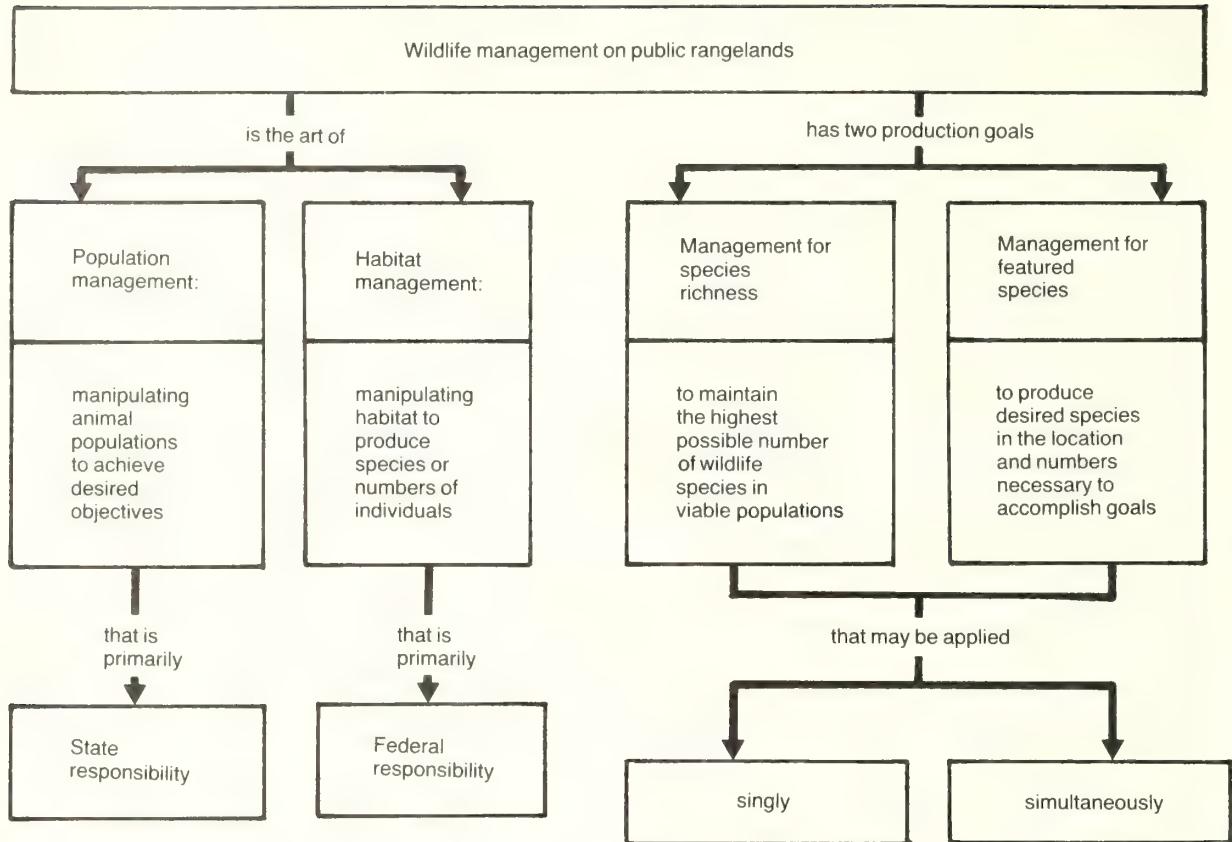


Figure 5.—The art and goals of wildlife management on public rangelands (adapted from Thomas 1979).

There are two general production goals in wildlife management—management for species richness (Evans 1974; Siderits 1975; USDA Forest Service 1973, 1975) and management for featured species (Holbrook 1974, USDA Forest Service 1971, Zeedyk and Hazel 1974) (fig. 6).

The goal of management for species richness is to insure that most resident wildlife species are maintained in viable numbers in the managed area (King 1966). Hence, all species are important. Management for species richness can be achieved by providing a broad spectrum of habitat conditions; characteristic stages or structural conditions of adequate size of each plant community should be represented in the

vegetative mosaic. It is therefore necessary to have information on the habitat needs of each species. This must then be incorporated into guides to protect the integrity, stability, and diversity of the rangeland ecosystem. The result should be a relatively stable and varied wildlife population.

Under management for featured species, the goal is to produce selected species in desired numbers in specific locations. This can be achieved by manipulating vegetation so the limiting factors of food, cover, and water are made less limiting for the desired species. These may be game species, threatened or endangered species, or species that have particular esthetic value.

Production goal	Management for species richness	Management for featured species
Objective	Insure that all resident species exist in viable numbers. All species are important.	Produce selected species in desired numbers in designated locations. Production of selected species is of prime importance.
Process	Manipulate vegetation so that characteristic stages of each plant community are represented in the vegetative mosaic.	Manipulate habitat factors so that limiting factors are made less limiting.

Figure 6.—Production goals in wildlife management (adapted from Thomas 1979).

Management for featured species has also been called “key-species management” or “indicator-species management” if the species selected represents the habitat needs of several species. If the species to be featured are carefully selected and their habitat needs vary widely, then management for featured species will also insure habitat diversity. The result can be similar to management for species richness.

The two management systems can also be simultaneously used to insure species richness while favoring selected species in specific locations for particular purposes. For example, management for species richness can be accomplished by providing an approximate mix of successional stages or stand conditions (structural conditions) within each plant community. Management for featured species can be accomplished by arranging stand size and successional stages to provide both cover and forage for selected species.

Rangelands are managed—that is, the vegetational composition and structure are controlled—through one or a combination of the following: (1) shrubs are controlled by mechanical means, herbicides, or fire; (2) controlled areas

are frequently seeded with grasses, forbs, and shrubs palatable and nutritious for livestock; and (3) grazing management, defined as “... manipulation of livestock grazing to accomplish a desired result” (Kothmann 1974, p. 36), is employed. Grazing management may include deferred grazing or use of a grazing system that is defined as “a specialization of grazing management which defines systematically recurring period of grazing and deferment for two or more pastures or management units” (Kothmann 1974, p. 36). Kothmann (1974) said there are many possible combinations of the four primary factors involved in any grazing system (number of pastures, number of herds, length of grazing periods, length of rest periods); but other factors, such as season of use, species of livestock, and class of livestock, must also be taken into account. In addition, such management involves livestock density and distribution of grazing within pastures or management units, which can be influenced by fencing, location of drinking water, or herding.

There are many options available to achieve the desired compositional and structural state of vegetation under the constraints of what the site can support, the availability of resources, and limitations of law, regulation, or custom. That the goals and objectives be clearly set and the progress toward those goals be periodically evaluated is of overriding importance. The goals and objectives must encompass both livestock production and wildlife habitat. It is essential that these goals and objectives be developed in conjunction with and cooperation between user groups and resource specialists and be stated in terms of vegetative condition first and numbers of outputs, such as animal unit months (AUM) of grazing or animal units (AU), second.

## The Setting

The Great Basin of southeastern Oregon falls mainly into the Owyhee Upland physiographic province and partly in the Basin and Range physiographic province (Franklin and Dyrness 1973) (fig. 1). It includes portions of Malheur and Harney Counties. The landscape is mostly rolling plateau at 1 066 meters (3,500 ft) in elevation, but there are mountains, cliffs, and canyons. Annual precipitation ranges from 18 to 30 centimeters (7 to 12 inches) (Heady and Bartolome 1977).

The Great Basin rangelands in southeastern Oregon support 28 plant communities dominated by grasses, shrubs, or trees. Trees vary from conifers to deciduous and evergreen hardwoods. Big sagebrush<sup>1</sup> communities predominate, whereas tree-dominated and true grassland communities constitute the least common types. True grasslands occur as relict meadows, relict stands of valley bottom bunchgrass, and relict subalpine bunchgrass types (Dealy et al. 1981, Maser and Strickler 1978).

<sup>1</sup> Scientific names are listed in the appendix.

Tree-dominated communities occur primarily at elevations above the sagebrush steppe, with the exception of low-elevation riparian willow and cottonwood communities. Quaking aspen is restricted primarily to mountain riparian zones associated with streams, seeps, springs, ponds, lakes, or snowdrift sites. With the exception of relict ponderosa pine and white fir, curlleaf mountainmahogany requires the most moisture of the dry-land tree types in the high desert mountains. Western juniper grows immediately below the curlleaf mountainmahogany and intermixes with it in transition zones. These tree-dominated communities are adjacent to and above the shrub zones (Dealy et al. 1981).

Big sagebrush, including several subspecies, dominates the shrub communities. Other significant tall shrub communities include black greasewood, squaw apple, Bolander silver sagebrush, and mountain silver sagebrush. Short shrub communities include shadscale saltbush, stiff sagebrush, low sagebrush, early low sagebrush, black sagebrush, and cleftleaf sagebrush (Dealy et al. 1981).

The diversity of topography and plant communities made the Great Basin of southeastern Oregon an ideal place to develop and test the range-wildlife management systems discussed in this series of papers.

The land ownership in the Great Basin of southeastern Oregon is shown in table 1. The Bureau of Land Management (BLM) controls the majority of the land (66 percent); 29 percent is in private ownership.

Agriculture and grazing of domestic livestock are the activities that dominate management of private land. Grazing of domestic livestock is the dominant use on BLM-administered lands. In 1980, 373 permittees ran 116,806 head of cattle and horses and 5,945 sheep composing 618,608 AUM on BLM lands (U.S. Department of the Interior, Bureau of Land Management 1981).

**Table 1—Land ownership in the Great Basin of southeastern Oregon**

Ownership	Hectares	Acres	Percent
<b>Bureau of Land Management</b>			
Management	3 025 792	7,476,881	66
Other Federal	62 506	154,456	1
State	174 944	432,296	4
Private	1 302 875	3,219,467	29
<b>Total</b>	<b>4 566 117</b>	<b>11,283,100</b>	<b>100</b>

Livestock management was facilitated on BLM lands in the Vale and Burns Districts from 1934 through 1981 by the following actions: Vegetation was manipulated on 140 770 hectares (347,702 acres); crested wheatgrass was seeded on 211 682 hectares (522,856 acres); 7 192 kilometers (4,469 mi) of fence was constructed; 477 cattle guards were installed; 1 611 kilometers (1,001 mi) of road was constructed to move livestock; 1 286 kilometers (799 mi) of water pipe was laid; 927 water storage tanks were built; 2,119 reservoirs were constructed; 749 springs were developed; and 121 wells were drilled (U.S. Department of the Interior, Bureau of Land Management 1981).

Extensive public ownership increases pressure from local governments for more intensive livestock management that, in turn, increases employment.

Livestock grazing has been relatively constant since the 1870's (Maser and Strickler 1978). The livestock industry of the area is strongly dependent on public rangelands, and it seems likely that there will be increasing pressure on the public rangelands of southeastern Oregon to provide red meat to sustain the local economy.

At the same time, these rangelands are being increasingly used for recreation. The number of people hunting and fishing has continued to grow. This results in more pressure to produce and sustain large numbers of game animals. The number of "rock hounds" has also increased. Such special use allocation will heighten pressure from industry and the public on managers of public rangelands to produce more red meat on fewer hectares (acres) at less cost to the livestock industry.

Increasing demands for more red meat, wildlife, fish, recreation, wilderness, and water from a finite land area inevitably lead to conflicts. Careful, farsighted management is necessary to obtain the desired wildlife and wildlife-related recreational experiences from such heavily managed rangelands.

## The Following "Chapters"

The following 13 "chapters" in this series are presented in a sequence designed to logically develop certain principles and ideas. Chapter 2 ("Plant Communities and Their Importance to Wildlife") describes the major plant communities and examines the importance of their structure and species composition to wildlife. It establishes the basis for discussion of vegetation and habitats that occur in all the chapters in this series.

Chapter 3, "The Relationship of Terrestrial Vertebrates to the Plant Communities," relates all terrestrial vertebrate species known to occur within the area to habitats associated by the plant communities described in chapter 2 and to subdivisions described by common structural conditions within those plant communities. The hypothesis is that each species is adapted to a particular habitat, and the likelihood of occurrence can be predicted by the quantity and quality of that habitat. The purpose is to allow the manager to deal simultaneously with all species in land-use planning or in preparing environmental analyses.

Chapters 4 through 9 were prepared in recognition that some species receive more attention than others in land-use planning and management. Or, as Orwell (1946, p. 112) put it: "All animals are equal but some animals are more equal than others." Federal agencies, for example, are required by law to pay particular attention to species designated as threatened or endangered. More attention is also paid to economically important species, such as game species, species trapped for furs, or species considered particularly interesting or esthetically pleasing. The chapters on native trout, ferruginous hawk, sage grouse, pronghorns, mule deer, and bighorn sheep are examples of how more extensive information can be provided for featured species.

Chapters 10 through 13 discuss special and unique habitats. Special habitats are biological in nature and can be at least partially controlled by the rangeland manager; they play a critical role in the lives of many species. These habitats include riparian zones and edges. Unique habitats are geomorphic in nature, usually cannot be easily manipulated to the advantage of wildlife, and are critical to certain species. These habitats are geomorphic and edaphic habitats and manmade habitats.

The chapter on management practices and options demonstrates how a manager can use management options to meet diverse wildlife goals and, at the same time, provide grazing for livestock. The message is that both wildlife and livestock management objectives can be met if the two are simultaneously derived and flexibility and careful planning are inherent in the process.

Together, these 14 chapters are an example of what can be done to provide the rangeland manager with the information necessary to fully consider wildlife in land-use planning, in preparing environmental impact statements, and in enhancing or protecting wildlife habitats.

## Acknowledgment

Ira D. ("Dave") Luman, former biologist with the Bureau of Land Management dedicated his career to enhancement or protection of wildlife habitats in the managed rangelands and forests of Oregon. He was the moving force behind the development of this series and worked diligently to insure the resources needed to develop, publish, and distribute this series.

## Literature Cited

- American Ornithologists' Union.  
1957. Check-list of North American birds. 691 p.  
Port City Press, Inc., Baltimore, Md.
- Bean, M. J.  
1977. The evolution of national wildlife. 485 p.  
Council on Environmental Quality, Washington,  
D.C.
- Bunnell, F. L.  
1976. The myth of the omniscient forester. *For.*  
*Chron.* 52(3):150-152.
- Commoner, B.  
1971. The closing circle: Nature, man, and  
technology. 326 p. Alfred A. Knopf, New York.
- Daubenmire, R.  
1976. The use of vegetation in assessing the pro-  
ductivity of forest lands. *Bot. Rev.* 42(2):115-143.
- Dealy, J. Edward, Donavin A. Leckenby, and Diane  
M. Concannon.  
1981. Wildlife habitats in managed rangelands—  
the Great Basin of southeastern Oregon: Plant  
communities and their importance to wildlife.  
USDA For. Serv. Gen. Tech. Rep. PNW-120, 66 p.  
Pac. Northwest For. and Range Exp. Stn., Port-  
land, Oreg.
- Evans, R. D.  
1974. Wildlife habitat management program: A  
concept of diversity for the public forests of Mis-  
souri. In *Timber-wildlife management sym-  
posium*. J. P. Slusher and T. M. Hinckley, eds. Mo.  
Acad. Sci. Occas. Pap. 3, p. 73-83. Columbia.
- Franklin, Jerry F., and C. T. Dyrness.  
1973. Natural vegetation of Oregon and  
Washington. USDA For. Serv. Gen. Tech. Rep.  
PNW-8, 417 p. Pac. Northwest For. and Range  
Exp. Stn., Portland, Oreg.
- Garrison, G. A., J. M. Skovlin, C. E. Poulton, and  
A. H. Winward.  
1976. Northwest plant names and symbols for  
ecosystem inventory and analysis. USDA For.  
Serv. Gen. Tech. Rep. PNW-46, 263 p. Pac. North-  
west For. and Range Exp. Stn., Portland, Oreg.
- Giles, R. H., Jr.  
1962. Timber-wildlife coordination concepts for  
eastern forests. *North Am. Wildl. and Nat. Re-  
sour. Conf. Trans.* 27:402-412.
- Giles, R. H., Jr., Ed.  
1971. Wildlife management techniques. 3d ed.  
633 p. Wildl. Soc., Wildl. Techniques Comm.,  
Washington, D. C.
- Heady, H. F., and J. Bartolome.  
1977. The Vale rangeland rehabilitation program:  
The desert repaired in southeastern Oregon.  
USDA For. Serv. Resour. Bull. PNW-70, 139 p.  
Pac. Northwest For. and Range Exp. Stn., Port-  
land, Oreg.
- Holbrook, H. L.  
1974. A system for wildlife habitat management  
of southern National Forests. *Wildl. Soc. Bull.*  
2(3):119-123.

- Hylander, C. J.  
1966. Wildlife communities from the tundra to the tropics in North America. 342 p. Houghton Mifflin Co., Boston, Mass.
- King, R. T.  
1966. Wildlife and man. N.Y. State Conserv. 20(6):8-11.
- Kothmann, M. M., Ed.  
1974. A glossary of terms used in range management. 2d ed. 36 p. Soc. Range Manage., Denver, Colo.
- Leopold, A.  
1933. Game management. 481 p. Charles Scribner Sons, New York.
- Margalef, R.  
1969. Diversity and stability: A practical proposal and a model of interdependence. In *Diversity and stability in ecological systems*. Brookhaven Symp. Biol. 22, p. 25-37. Brookhaven Natl. Lab., Upton, N.Y.
- Maser, Chris, and Gerald S. Strickler.  
1978. The sage vole, *Lagurus curtatus*, as an inhabitant of subalpine sheep fescue, *Festuca ovina*, communities on Steens Mountain – an observation and interpretation. Northwest Sci. 52(3): 276-284.
- Meslow, E. C., and H. W. Wight.  
1975. Avifauna and succession in Douglas-fir forests of the Pacific Northwest. In *Proceedings of the symposium on management of forests and range habitats for nongame birds*. D. R. Smith, ed. USDA For. Serv. Gen. Tech. Rep. WO-1, p. 266-271. Washington, D.C.
- Odum, E. P.  
1963. Ecology. 152 p. Holt, Rinehart, and Winston, Inc., New York.
- Odum, E. P.  
1971. Fundamentals of ecology. 3d ed. 574 p. W. B. Saunders Co., Philadelphia, Pa.
- Orwell, G.  
1946. Animal farm. 118 p. Harcourt, Brace, and Co., Inc., New York.
- Patton, D. R.  
1975. A diversity index for quantifying habitat "edge." Wildl. Soc. Bull. 3(4):171-173.
- Siderits, K.  
1975. Forest diversity: An approach to forest wildlife management. For. Chron. 51(3):1-5.
- Taylor, Walter P., Ed.  
1956. Preface. In *The deer of North America: The white-tailed, mule and black-tailed deer, genus Odocoileus, their history and management*, p. ix-xi. Stackpole Co., Harrisburg, Pa., and Wildl. Manage. Inst., Washington, D.C.
- Thomas, Jack Ward, Glenn L. Crouch, Roger S. Bumstead, and Larry D. Bryant.  
1975. Silvicultural options and habitat values in coniferous forest. In *Proceedings of the symposium on management of forest and range habitats for nongame birds*. D. R. Smith, ed. USDA For. Serv. Gen. Tech. Rep. WO-1, p. 272-287. Washington, D.C.
- Thomas, Jack Ward, Tech. Ed.  
1979. Wildlife habitats in managed forests: The Blue Mountains of Oregon and Washington. U.S. Dep. Agric. Agric. Handb. 553, 512 p. U.S. Gov. Print. Off., Washington, D.C.
- Trippensee, R. E.  
1948. Wildlife management: Upland game and general principles. Vol. 1. 479 p. McGraw-Hill Book Co., Inc., New York.
- U.S. Department of Agriculture, Forest Service.  
1971. Wildlife habitat management handbook, Southern Region, FSH 2609.23R. 189 p. U.S. Dep. Agric. For. Serv. Reg. 8, Atlanta, Ga.
- U.S. Department of Agriculture, Forest Service.  
1973. Wildlife habitat management guide for the National Forests in Missouri. 42 p. Mark Twain Natl. For., Rolla, Mo. [In cooperation with the Mo. Dep. Conserv.]
- U.S. Department of Agriculture, Forest Service.  
1975. Fisheries and wildlife habitat management handbook, Ottawa, Hiawatha, and Huron-Manistee National Forests, Michigan, FSH 2609.23-R9. U.S. Dep. Agric. For. Serv. Reg. 9, Milwaukee, Wis.
- U.S. Department of the Interior, Bureau of Land Management.  
1981. BLM facts – Oregon and Washington. 36 p. U.S. Dep. Inter., Bur. Land Manage., Washington, D.C.
- U.S. Laws, Statutes, etc. Public Law 85-624. [H.R. 13138],  
August 12, 1958. To amend the Act of March 10, 1934, to provide for more effective integration of a fish and wildlife conservation program with Federal water-resource developments, and for other purposes. In its United States statutes at large. 1958. Vol. 72, p. 563. U.S. Gov. Print. Off., Washington, D.C., 1959. [16 U.S.C. sec. 661-664 (1959).]
- U.S. Laws, Statutes, etc. Public Law 86-517. [H.R. 10572],  
June 12, 1960. An act to authorize and direct that the National Forests be managed under principles of multiple use and to produce a sustained yield of products and services, and for other purposes. In its United States statutes at large. 1960. Vol. 74, p. 215. U.S. Gov. Print. Off., Washington, D.C., 1961. [16 U.S.C. sec. 528-531 (1976).]
- U.S. Laws, Statutes, etc. Public Law 91-135. [H.R. 11363],  
December 5, 1969. Endangered Species Conservation Act of 1969. In its United States statutes at large. 1969. Vol. 83, p. 275. U.S. Gov. Print. Off., Washington, D.C., 1970. [16 U.S.C. sec. 688 (1970).]

U.S. Laws, Statutes, etc. Public Law 91-190.

1969. [S. 1075], Jan. 1, 1970. National Environmental Policy Act of 1969. An act to establish a national policy for the environment, to provide for the establishment of a Council on Environmental Quality, and for other purposes. *In its United States statutes at large*. 1969. Vol. 83, p. 852-856. U.S. Gov. Print. Off., Washington, D.C., 1970. [42 U.S.C. sec. 4321, et seq. (1970).]

U.S. Laws, Statutes, etc. Public Law 93-205. [S. 1983],

December 28, 1973. Endangered Species Act of 1973. *In its United States statutes at large*. 1973. Vol. 87, p. 884. [16 U.S.C. sec. 668 (1976).]

U.S. Laws, Statutes, etc. Public Law 93-378. [S. 2296],

August 17, 1974. Forest and Rangeland Renewable Resources Planning Act of 1974. An act to provide for the Forest Service, Department of Agriculture, to protect, develop, and enhance the productivity and other values of certain of the Nation's lands and resources, and for other purposes. *In its United States statutes at large*. 1974. Vol. 88, Part 1, p. 476-480. U.S. Gov. Print. Off., Washington, D.C., 1976. [16 U.S.C. sec. 1601 (1976).]

U.S. Laws, Statutes, etc. Public Law 93-452. [H.R. 11537],

October 18, 1974. An act to extend and expand the authority for carrying out conservation and rehabilitation programs on military reservations and to authorize the implementation of such programs on certain public lands. *In its United States statutes at large*. 1974. Vol. 88, p. 1369. U.S. Gov. Print. Off., Washington, D.C., 1976. [16 U.S.C. sec. 670 (1976).]

U.S. Laws, Statutes, etc. Public Law 90-2743.

1976. Oct. 21, 1976. Federal Land Policy and Management Act of 1976. [43 U.S.C. 1701 (note).]

Walker, E. P., F. Warnick, S. Hamlet, and others.

1975. Mammals of the world. 3d ed. 1,500 p. Johns Hopkins Univ. Press, Baltimore, Md.

Zeedyk, W. D., and R. B. Hazel.

1974. The southeastern featured species plan. *In* Timber-wildlife management symposium. J. P. Slusher and T. M. Hinckley, eds. Mo. Acad. Sci. Occas. Pap. 3, p. 58-62. Columbia.

## Appendix

### COMMON AND SCIENTIFIC NAMES

Common name	Scientific name
<b>MAMMALS<sup>1</sup></b>	
Bighorn sheep	<i>Ovis canadensis</i>
Cattle	<i>Bos taurus</i>
Domestic sheep	<i>Ovis aries</i>
Horse	<i>Equus caballus</i>
Mule deer	<i>Odocoileus hemionus</i>
Pronghorn	<i>Antilocapra americana</i>
<b>BIRDS<sup>2</sup></b>	
Ferruginous hawk	<i>Buteo regalis</i>
Sage grouse	<i>Centrocercus urophasianus</i>
<b>SHRUBS<sup>3</sup></b>	
Big sagebrush	<i>Artemisia tridentata</i>
Black greasewood	<i>Sarcobatus vermiculatus</i>
Black sagebrush	<i>Artemisia nova</i>
Bolander silver sagebrush	<i>Artemisia cana</i> subsp. <i>bolanderi</i>
Cleftleaf sagebrush	<i>Artemisia arbuscula</i> subsp. <i>thermopola</i>
Early low sagebrush	<i>Artemisia longiloba</i>
Low sagebrush	<i>Artemisia arbuscula</i> subsp. <i>arbuscula</i>
Mountain silver sagebrush	<i>Artemisia cana</i> subsp. <i>viscidula</i>
Sagebrush	<i>Artemisia</i> sp.
Shadscale saltbush	<i>Atriplex confertifolia</i>
Squaw apple	<i>Peraphyllum ramosissimum</i>
Stiff sagebrush	<i>Artemisia rigida</i>
<b>TREES<sup>3</sup></b>	
Cottonwood	<i>Populus</i> sp.
Curlleaf mountainmahogany	<i>Cercocarpus ledifolius</i>
Ponderosa pine	<i>Pinus ponderosa</i>
Quaking aspen	<i>Populus tremuloides</i>
Western juniper	<i>Juniperus occidentalis</i>
White fir	<i>Abies concolor</i>
Willow	<i>Salix</i> sp.
<b>GRASS AND GRASSLIKE PLANTS<sup>3</sup></b>	
Crested wheatgrass	<i>Agropyron cristatum</i> or <i>Agropyron desertorum</i>

<sup>1</sup> After Walker et al. (1975).

<sup>2</sup> After American Ornithologists' Union (1957).

<sup>3</sup> After Garrison et al. (1976).







**WILDLIFE HABITATS IN MANAGED RANGELANDS — THE  
GREAT BASIN OF SOUTHEASTERN OREGON**

**Technical Editors**

**JACK WARD THOMAS, U.S. Department of Agriculture,  
Forest Service**

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# Red Alder: A Bibliography With Abstracts



Cover photo:

A stand of red alder at Cascade Head Experimental Forest near Otis, Oregon. The trees are from 14 to 20 inches in diameter. (U.S. Forest Service photo 325534)

USDA Forest Service General Technical Report PNW-161

## **Red Alder: A Bibliography With Abstracts**

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## Abstract

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abstracts. Gen. Tech. Rep. PNW-161.  
Portland, OR: U.S. Department of  
Agriculture, Forest Service, Pacific  
Northwest Forest and Range Experiment  
Station; 1983. 186 p.

This bibliography lists 661 references  
to world literature through May 1978  
containing information about red alder  
(Alnus rubra Bong.). Included are  
publications about its taxonomy, biology  
and silvics, chemical and physical information  
about its wood and fiber, studies  
on its nitrogen-fixing properties, and  
reports on industrial uses and economic  
considerations. Sources of cited publications  
are scientific journals, trade  
publications, special reports, and popular  
books. Abstracts or annotations  
are included for many references.  
Subject matter and author indexes are  
included.

Keywords: Red alder, Alnus rubra,  
bibliographies (forestry).

## Introduction

This bibliography contains citations of literature containing information about red alder (Alnus rubra Bong.). It is the result of organizing references collected for several red alder projects and is offered as an aid to additional study on red alder.

Our search covered all index issues of Biological Abstracts, Chemical Abstracts, Forestry Abstracts, and Science Citation Index. We used computer bibliographic services to obtain citations from BIOSIS REVIEWS, CAB, CAIN, CHEMCON, PAPERCHEM, and CRIS data bases from the time of their establishment through May 1978. There were no articles about red alder in the journal Aliso. Bibliographies of most papers cited here were checked for articles not included in the above search procedure.

Our search was designed to exclude articles about individual fungi and diseases attacking red alder and about palynology, the study of pollen stratigraphy; however, some citations to both are included. Fungi and disease are adequately covered in the works of Browne (83), Hepting (237), Peace (445), and Shaw (511, 512, 513, 514), each of which provides further references to original papers. We include articles on red alder outside forestry to broaden the scope of usefulness and to increase the number of potential users.

Citations without abstracts or annotations are papers of lesser importance or papers not seen by us but authoritatively cited by others. These are included because of their potential value to readers. References are listed alphabetically by author. A subject matter index is included.

A copy of most cited works is on file at either the Forestry Sciences Laboratory, 3625 93rd Avenue S.W., Olympia, Washington 98502, or the Forest Land Management Center, Department of Natural Resources, Olympia, Washington 98504. All are readily accessible in major libraries or through the USDA Forest Service WESTFORNET information system.

We will appreciate hearing of additional documents about red alder published before May 1978.

## Acknowledgments

Thanks are extended to Boyd C. Wilson, Washington State Department of Natural Resources; Dean S. DeBell and Arland S. Harris, Forest Service, U.S. Department of Agriculture; John C. Gordon, Oregon State University, for permission to use their personal libraries; and to Shirley Beelik, Washington State Library, and Thelma Sameth, University of Washington Forestry Library, for their assistance. Special thanks to Dean S. DeBell and Constance A. Harrington for their help with the subject index.

**ABBREVIATIONS**

	<b>ABSTRACTOR</b>
A	Author
BA	Biological Abstracts
BI	Biological Index
CFH	Charles F. Heebner
CA	Chemical Abstracts
FA	Forestry Abstracts
PO	Plant Breeding Abstracts
EO	Review of Applied Entomology, Series A
MO	Review of Plant Pathology
SO	Soils and Fertilizers
WO	Weed Abstracts

1. Abbe, Ernst C.  
1935. Studies in the phylogeny of the Betulaceae. I. Floral and inflorescence anatomy and morphology. *Bot. Gaz.* 97(1):1-67.
2. Abbe, Ernst C.  
1938. Studies in the phylogeny of the Betulaceae. II. Extremes in the range of variation of floral and inflorescence morphology. *Bot. Gaz.* 99(3):431-469.  
  

"A study of the morphology and vascularization of the cymules and florets of 64 spp. and vars. of the Betulaceae from each of the genera and subgenera indicates the following: (1) The morphology and anatomy of the cymules and florets has been notably modified by dorsiventral or lateral concrescence, shortening of internodes, pressures within the ament, and reduction; (2) the bicarpellary ovaries owe their transverse or diagonal orientation to their derivation from the ancestral tri-carpellary ancestor, while the staminate florets in some spp. still are trimerous; (3) the full complement of bracts is present in the pistillate cymules of Carpinus, Ostryopsis, and Ostrya, the adaxial tertiary bract is lost from the staminate and pistillate cymules of most species of Alnus. Both adaxial and abaxial tertiary bracts have been lost from the staminate cymules of Betula, Corylus, Carpinus, Ostrya, and from the pistillate cymules of Betula. The secondary bracts have been lost, while the tertiary persist, in the pistillate cymules of Corylus. All bracts but the primary have been lost in the staminate cymules of Ostryopsis. (4) The staminate cymule is 3-flowered in all genera of the family. The pistillate cymule is 2-flowered by suppression of the secondary floret in all genera except Betula, in which all 3 florets are present. (5) The perigon is present in the pistillate florets of Carpinus, Ostrya, Corylus, Ostryopsis, and in the staminate florets of Alnus and Betula; it is obsolescent in the pistillate florets of Alnus and Betula; it is completely lost from the staminate florets of Carpinus, Corylus, and Ostryopsis. The ovary is inferior throughout the family." (BA)
3. Abrams, L., and Roxana S. Ferris.  
1940. Illustrated flora of the Pacific States. Vol. 1. 538 p. Stanford Univ. Press, Stanford, Calif.
4. Akkermans, Antonius Dirk Louis.  
1971. Nitrogen fixation and nodulation of Alnus and Hippophae under natural conditions. Ph. D. thesis. Univ. Leiden, The Netherlands. 85 p.  
  

Detailed discussion of procedures and techniques for studying nitrogen fixation by alder in field and in laboratory. Covers both N-15 and acetylene-reduction methods. (CFH)

5. Alban, David H.  
1969. The influence of western hemlock and western redcedar on soil properties. *Soil Sci. Soc. Am. Proc.* 33(3):453-457.

"Soils beneath very old western hemlock (Tsuga heterophylla (Raf.) Sarg.) and western redcedar (Thuja plicata Donn) trees at three sites on Washington and Idaho were compared. The sites differed in climate and parent materials, but were similar to the extent that western hemlock and western redcedar dominated the overstory. The A2-B2 sequences were generally more strongly developed under hemlock than under cedar. At two of the three sites considerable mixing of the organic and mineral soil horizons had occurred under cedar, but much less so under hemlock. Below the top 15 cm of mineral soil no large morphological differences were observed between profiles under cedar and hemlock. Soil pH, 'exchangeable' Ca, cation-exchange capacity, base saturation, and the total weight of organic horizons were greater under cedar than under hemlock. Soil N, C, Mg, and K were generally higher under cedar than under hemlock but the differences were not large. The differences between soil properties under hemlock and cedar, as well as the depth to which these differences occurred, varied from one property to another, and from site to site." (A)

6. Allan, G. G., C. S. Chopra, J. F. Friedhof, R. I Gara, M. W. Maggi, A. N. Neogi, S. C. Roberts, and R. M. Wilkins.  
1973. Pesticides, pollution and polymers. *Chem. Technol.* 4(3):171-178.

"Ways of reducing pesticide applications using controlled release formulations, the chemistry of the controlled release

from the polymeric matrix and the advantages and applications of polymerized controlled release pesticides are reviewed. In field trials, ester combinations of 2,4-DB with bark were synthesized; the polymerized pesticide resists oxidation in the soil to 2,4-D (which is more toxic to conifers than 2,4-DB) and had an extended duration of effectiveness. The polymerized 2,4-DB controlled Alnus rubra without harming Douglas-fir (Pseudotsuga menziesii). (WO)

7. Allan, G. G., Astrid Lacitis, Fu-mei Liu, J-h Lee, and P. Mauranen.  
1969. Fiber surface modification. Pt. II. Modification of ligniferous wood and bark fibers using a dichloro-s-triazine. *Holzforschung* 23(6):198-202.

"The application of the fundamentals of the reactive dye chemistry originally developed for textiles is proposed as a new general approach to the surface modification of wood fibers. The reactivities of a variety of lignaceous wood and bark fibers with a dihalogeno-s-triazine fiber reactive dye have been compared under conditions compatible with current board and paper manufacturing techniques. Differences in the extent of reaction are ascribed to the morphological characteristics of the fiber and to the type and amount of its lignin or phenolic group content. The dyed fibers contain a reactive monochloro-s-triazine moiety the chlorine atom of which however could not be displaced by either phenolate or thiophenolate anions. This inhibition of the chlorine displacement is attributed to a combination of steric effects due to the fiber mass and the electrokinetic repulsions occasioned by the sulfonic acid groups incidentally present as part of the structure of the reactive dye molecule." (A)

8. Allan, G. Graham, Chetan S. Chopra, and Robert M. Russell.  
1972. Controlled release pesticides. Part 3. Selective suppression of weeds and deciduous brush in the presence of conifers. Int. Pest Control 14(2):15, 17-20.

"In the USA reafforestation with conifers is nationally retarded by the root competition offered by weeds and by the more rapidly growing deciduous brush and no satisfactory herbicide selectively toxic to these competitors has hitherto been developed. The synthesis of such a material has now been achieved by the chemical reaction of 2,4-DB with comminuted bark to afford a controlled release herbicide polymer combination. The macromolecular herbicide derivative at specific application levels did not damage Douglas-fir (Pseudotsuga menziesii) seedlings and yet had the capability of eradicating established western red alder (Alnus rubra) seedlings whilst simultaneously inhibiting weed seed germination and growth for an entire growing season. The selectivity observed is attributed to the release of 2,4-DB from combination with the bark polymers at a controlled rate which is sufficiently slow for its absorption by all plants to occur before enzymic degradation to the generally phytotoxic 2,4-D can take place in the soil." (WO)

9. Allison, G. W., and R. E. Breadon.  
1960. Timber volume estimates from aerial photographs. B.C. For. Serv. For. Surv. Note 5, 25 p. Dep. Lands and For., Victoria, B.C.

10. Altmann, Th.  
1940. Die erle als verwald.  
Forstarchiv 16 (6/7):92-93.

"Large areas of pine forest in the Nuremberg Reichswald were killed by the pine looper in the 1890's and the young stands established on the same areas were largely destroyed by Panalis flammnea when about 30 years old. Pine monoculture accounts for the severity of the damage. To avoid such losses in the future, pine, spruce, and alder were mixed in the recent plantations. Both red and white alder grew vigorously on the coarse sandy soil where it was plowed deeply, limed, and cleared of competing vegetation. The alder created favorable conditions for the conifers, which promise to make a highly productive forest, resistant to insect attack. Black locust and Canadian poplar were also tried as nurse trees, but suffered from frost and drought. Birch was almost as good as alder, but was heavily browsed by deer." (BA)

11. Amchem Products, Inc.  
1960. Amitrol, benzac, and combinations of both for control of woody plants. Tech. Serv. Data Sheet, Ambler H-79, 5 p.

"Presents a list, compiled from published and unpublished work, of wood plants susceptible (i.e., kill of 85% of the stem, with little or no regrowth after 2 growing seasons) to various rates of Amizol (90% active water-soluble formulation of amitrol), Benzac 1281 (2 lb./gal. triethylamine salt of 2,3,6-TBA) or a mixture of the two. Results from unpublished work were: Acer macrophyllum and Rubus spp. susceptible to Amizol 4 lb./100 gal.; R. spectabilis, Alnus rubra, A. macrophyllum, Salix spp., Tsuga heterophylla, and Abies grandis susceptible to Benzac 1281 4 lb./100 gal." (FA)

12. Amchem Products, Inc.

1962. Oil-soluble amines of 2,4-D and 2,4,5-T for the control of woody plants and broadleaf weeds. Tech. Serv. Data Sheet, Ambler E-162, 15 p.

"Volatility studies comparing various low-volatile ester, acid and water- and oil-soluble amine formulations of 2,4-D and 2,4,5-T are summarized, and methods of application to various weed and brush species used in comparisons of different oil-soluble and standard formulations of 2,4-D and/or 2,4,5-T and fenoprop are given. Tables give data of the degree of control of a wide range of different weed, brush and tree species obtained by the use of the oil-soluble amine formulations. The tree and brush species included Sassafras albidum, Quercus borealis, Q. marilandica, Q. falcata, Q. stellata, Q. alba, Prunus serotina, Nyssa sylvatica, Liriodendron tulipifera, Acer rubrum, Robinia pseudoacacia, Fraxinus americana, Q. ilicifolia, Hamamelis virginiana, Rubus spp., Malus spp., Cornus florida, C. paniculata, Ulmus americana, Carya spp., Sambucus canadensis, Crataegus spp., Salix spp., Viburnum spp., Rhus glabra, Pinus ponderosa, Picea sitchensis, Populus sp., Pseudotsuga taxifolia, Tsuga heterophylla, Alnus rubra, Gualtheria shallon, Mahonia aquifolium, Ceanothus velutinus, Abies grandis, Rubus leucodermis, Rubus spectabilis, Liquidambar styraciflua and Tamarix pentandra. The results of volatility studies indicated that at high temperatures the oil-soluble amine formulations were considerably less volatile than the low-volatile esters, and were of about the same volatility as the water-soluble amines. In three trials in which low rates and spray volumes were used, the oil-soluble amines did not appear to be as effective as the low-volatile esters, and approximated to the water-soluble amines in effect. The reasons for this were not apparent. Against woody plants, the greater effec-

tiveness of oil-soluble amines when concentrated around the root-collar zone, compared with applying them as stem-foliage sprays, was noted. It was concluded that the oil-soluble amines offer major advantages over water-soluble amines. They can be used in oil, oil/water, and water carriers, and, at high temperatures, the oil-soluble amines of phenoxy compounds can be expected to show only low volatility hazards, compared with standard formulations." (FA)

13. American Forestry Association.

1973. AFA's social register of big trees. Am. For. 79(4):21-74.

Largest red alder near Gardiner, Oregon, found by Francis Kimmey of Veneta, Oregon, is 15 feet in diameter at breast height, 99 feet high, with a spread of 76 feet. (CFH)

14. American Plywood Association.

1974. U.S. Product Standard PS 1-74 for construction and industrial plywood with typical APA grade-trademarks. 35 p. Prod. Stand. Sect., Natl. Bur. Stand., Tacoma, Wash.

Describes manufacturing standards for plywood. Red alder is acceptable and is interchangeable with all species within group 3. (CFH)

15. Andersen, H. E.

1955. Alder control on cutover areas. Alaska For. Res. Cent. Tech. Note 25, 1 p.

"Alder on a deep alluvial flat, logged in 1954, was treated by poisoning with NH<sub>4</sub> sulphamate, applied in cups at 8-in. intervals round the root collar

or, for smaller trees, by felling and poisoning the stumps. Treatment was on 22 June, and at the end of 2 months the cambium was dead in practically all trees. No viable seed was produced by the treated trees." (FA)

16. Anderson, B. G., and R. G. Frashour. 1954. Sticker stain in one-inch red alder lumber. For. Prod. Res. Soc. J. 4(3):133-135.

"Experiments showed that stain developing at sticker crossings in air-drying 1 inch Alnus rubra could be prevented by steaming the stickered lumber beforehand, and that this treatment also gave a desirable and uniform colour in the timber after final drying. Optimum treatment appeared to be 140° F. dry-bulb temperature and 4° F. wet-bulb depression and a minimum steaming time of about 18 hours. This method allows full advantage to be taken of air-drying during the summer without loss caused by stain or undesirable colour, and a reduction of 2-4 days in total kilning time." (FA)

17. Anderson, B. G., and R. G. Frashour. 1954. Sticker stain in one-inch red alder lumber. Rep. Oreg. For. Prod. Lab. D-3, 6 p.

"Experiments showed that stain developing at sticker crossings in air-drying 1-in. Alnus rubra could be prevented by steaming the stickered lumber beforehand, and that this treatment also gave a desirable and uniform colour in the timber after final drying. Optimum treatment appeared to be 140° F. dry-bulb temperature and 4° F. wet-bulb depression and a minimum steaming time of ca. 18 hr. This method allows full advantage to be taken of air-drying during the summer without loss caused by stain or undesirable colour, and a reduction of 2-4 days in total kilning time." (FA)

18. Andrews, H. J., and R. W. Cowlin. 1940. Forest resources of the Douglas-fir region. U.S. Dep. Agric. Misc. Publ. 389, 169 p. U.S. Gov. Print. Off., Washington, D. C.

Contains two red alder volume tables. (CFH)

19. Angulo, A. F., C. van Dijk, and A. Quispel. 1976. Symbiotic interactions in non-leguminous root nodules. In Symbiotic nitrogen fixation in plants, p. 475-483. P. S. Nutman, ed. Cambridge Univ. Press, England.

A general discussion of the biology of the alder root endophyte. The life cycle, probable method of infections, and techniques for cultivation of the root endophyte are covered. (CFH)

20. Apsey, T. Michael. 1961. An evaluation of crown widths of open-grown red alder as an aid to the prediction of growth and yield. B.S.F. thesis. Univ. B. C., Vancouver. 67 p.

"The growth and yield of Alnus rubra was studied, and crown-width/d.b.h. relationships were determined for both (1) open- and (2) close-grown trees. It was shown that, for both (1) and (2), most of the variation in crown width was accounted for by d.b.h., and a crown-width yield table was developed. Several multiple-regression equations were derived to provide estimates of radial growth, (a) 1-5 years ago, and (b) 6-10 years ago. It was found that for (1) most of the variation in radial growth (a) was accounted for by the variables total age and radial growth (b). For (2), however, most of the variation in radial growth (a) was accounted for by the variables d.b.h. and % live crown." (FA)

21. Arkwright, Peter.  
1963. Know your timber. Woodworking Ind. 20(1-3):45, 89, 151.

"Rock elm (Ulmus thomasii); Opepe (Sarcocephalus diderrichii); and Western Red Alder (Alnus rubra)."  
(FA)

22. Atkinson, William A., and Willard I. Hamilton.

1978. The value of red alder as a source of nitrogen in Douglas-fir/alder mixed stands. In Utilization and management of alder, p. 337-351. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Numerous studies of forest fertilization have demonstrated that Douglas-fir stands in the Pacific Northwest and British Columbia grow better when fertilized with nitrogen. Since the long-term outlook for fertilizer supply and cost is uncertain, foresters should be examining alternatives for maintaining and increasing forest productivity. Several nitrogen-supplying species of plants exist, of which red alder is the most interesting. Alder not only imparts significant amounts of nitrogen to the forest soil, but also is a tree of increasing value for wood products."

"This paper examines the economic value of alder both as a source of nitrogen and for its wood value. Three approaches are taken: (1) An economic analysis is made of existing research plot data on the Wind River Experimental Forest. Results are contrasted with the alternative of artificial fertilization. (2) Investigations of the nitrogen supplying capability of red alder reveal that relatively few alders are needed in order to supply Douglas-fir with its

nitrogen needs. (3) A general model is proposed for evaluating alder's place in Douglas-fir forest management. Data requirements are identified." (A)

23. Atterbury, Toby.

1978. Alder characteristics as they affect utilization. In Utilization and management of alder, p. 71-81. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The utilization of red alder in the Pacific Northwest is tied to its location, yield, tree size, and wood properties. Up to the present time, conifers have been utilized and managed because they are more profitable. When the older stands of large conifers are harvested, alder may become fully utilized on its own merits." (A)

24. Baber, A. A., and G. L. McCall.

1974. "Krenite" - a new brush control agent. West. Soc. Weed Sci. Proc. 27:4-5.

"Foliage sprays of Krenite (ammonium ethyl carbamoylphosphonate) made after the main flush of annual growth has hardened, eliminate unwanted brush without unsightly discoloration. Leaf fall of susceptible plants occurs normally in the autumn but subsequent bud development is prevented or severely limited and stems and roots eventually die. Effective rates range from 4-8 lb/acre (aerial application) and from 2-6 lb/acre (ground application). Susceptible brush plants include Acer circinatum, Alnus rubra, Rubus spectabilis, Quercus spp., Eucalyptus spp., and Sequoia sempervirens. Herbaceous plants and broad-leaved evergreens are not affected." (WO)

25. Baird, P. K., J. S. Martin, and D. J. Fahey.  
1955. Bond and magazine book papers and milk-carton paperboard from old-growth Douglas-fir and red alder pulps. USDA For. Serv. For. Prod. Lab. Rep. 2042, 13 p. Madison, Wis.

"Experimental processes tried at Madison point to the possibility of commercial application of Douglas-Fir bleached sulphate pulp, with or without Red-Alder pulp (groundwood, chemiground, or neutral sulphite)." (FA)

26. Baker, William J.  
1951. Some factors involved in the promotion of alder-using industries in Tillamook, Oregon. Oreg. For. Prod. Lab. Spec. Rep. 1, 35 p. Sch. For., Oreg. State Coll. [Univ.], Corvallis.

27. Balci, A. N.  
1964. Physical, chemical, and hydrological properties of certain western Washington forest floor types. Ph. D. thesis. Univ. Wash., Seattle.  
206 p.

"Two major types--(a) mor, (b) duff mull--from 5 major areas of old-growth coniferous forests were studied. Distinct differences observed were: (1) Total weight and depth were greater for (a) than for (b). (2) Ignition losses of (a) were significantly greater, because (b) has a higher mineral dilution due to a gradual transition of the H layer to the A<sub>1</sub> horizon. (3) (a) had higher moisture constants and lower bulk densities than (b). (4) In the same rainfall conditions, the hydrograph for (a) had more gentle slopes on both ascending and recession periods; the shape of the hydrograph was affected by the

depth of the forest floor. (5) Concentrations of N, P, and K were higher in (b), and total C, specific conductance, and C/N ratios in (a). These characteristics are believed to be indicative of differential decomposition rates, leaching of elements and age of forest floor. (6) (a) was more acid than (b). Rainfall of 15 cm/hour was transmitted at the same rate in (a) and (b), and both types had a higher effective saturation capacity at the steady-flow stage under 15 cm than under 2-3 cm rain/hour. In a study from October to May in (c) a young Red Alder stand and (d) Douglas Fir, the forest floor of (c) decomposed more rapidly and there were greater monthly fluctuations in the elemental composition of (c) leachates; (c) forest floors imparted a much darker colour to the natural waters than (d), but leachates of both were coloured far above permissible limits for domestic use. The pH of the surface water was low for (c), and leachates from (c) had higher concentrations of N, P, K, Ca, Mg and tannin and lignin compounds. The magnitude of elemental release from the forest floor of (c) was K > Ca > Mg > N > P, and that of leaching of nutrients beyond the 15-cm level was Ca > Mg > K > N > P." (FA)

28. Balci, A. N.  
1973. Physical, chemical and hydrological properties of certain western Washington forest floor types. Istanbul Univ. Orman Fak. Yayin. 200, 159 p.

"The full version of work already noticed from a dissertation abstract on the characteristics of the forest floor under old-growth conifer stands and a 30-year-old Alnus rubra stand, and including a brief general review of the morphological classification and properties of forest floor and humus types." (FA)

29. Barber, Paul, Marvin Noble, and Juel Sheldon.  
 1978. Buyer's perspective on public agency timber sale procedures for alder. (Abstr.) In Utilization and management of alder, p. 83. David G. Briggs, Dean S. Debell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
30. Barrett, R. E.  
 1932. New coleoptera from California. Pan-Pac. Entomol. 8(4):171-172.
- "Dendroides pacificus (p. 171), breeding in trunk of Alnus rubra, also inhabited by Platycerus oregonensis; Tamnochila sonorana (p. 171), under bark of Prosopis juliflora glandulosa; Aphodius sparsus ssp. shaldoni (p. 172), in nests of wood rat, Neotoma." (BA)
31. Becking, J. H.  
 1965. In vitro cultivation of alder root-nodule tissue containing the endophyte. Nature 207(4999):885-887.
- "Though culture in vitro of root-nodule tissue containing the endophyte was successful, the main object of the investigation--culture of the effective nodule-endophyte of Alnus glutinosa in symbiosis with its host in vitro--was not achieved. The root-nodule tissue grown in vitro and containing its endophyte is a simpler system than that obtained in leguminous symbiosis." (FA)
32. Becking, J. H.  
 1966. Interactions nutritionnelles plantes-actinomycetes. [Nutritional interactions between plants and actinomycetes.] Rapp. Gen. Ann. Inst. Pasteur (Paris) Suppl. 111:211-246. [In French. English summary.]
- "The present report reviews the available information about non-leguminous plants which have the capacity to fix molecular nitrogen. Many unpublished results obtained by the author are included.
- "An enumeration is given of the nodule-bearing non-leguminous plants, the nodule-bearing habits within each group, the cross-inoculation groups and the biological function of the root nodules.
- "A brief survey is given of the biochemical characteristics of the root nodules, the nodule morphology and cytology. A morphological and cytological description of the endophyte is given. Experiments are described for the isolation of the endophyte with the aid of root-nodule tissue cultures." (A)
33. Becking, J. H.  
 1968. Nitrogen fixation by non-leguminous plants. Dutch Nitrogen Fert. Rev. 12:47-74.
34. Becking, J. H.  
 1970. Frankiaceae fam. nov. (Actinomycetales) with one new combination and six new species of the genus Frankia Brunchorst 1886, 174. Int. J. Syst. Bacteriol. 20(2): 201-220.
- "The purpose of this publication is to propose a new taxonomic treatment of an important group of bacteria, which produce nodules on the roots of non-leguminous dicotyledons. The root nodule, product of the symbiosis of host and

bacteria, is able to fix atmospheric nitrogen. A single family, a single genus, and ten species are recognized." (A)

35. Becking, J. H.

1972. De betekenis van de rode els (Alnus rubra) voor de teelt van de douglasspar (Pseudotsuga menziesii). [The role of the red alder (Alnus rubra) in the cultivation of the Douglas-fir (Pseudotsuga menziesii.) Ned. Bosbouw Tijdschr. 44(5):132-137. [In Dutch.]

"Reviews experience in the USA and discusses the desirability of trials of mixtures of A. rubra and P. menziesii in Europe." (FA)

36. Behm, R. D.

1978. Developing new alder markers. In Utilization and management of alder, p. 157-161. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Attitude toward alder will play an important role in its future. Alder must be recognized as a species which produces a positive contribution to the local economy. The alder image can be improved by dropping the word 'red' from its name and by promoting it as an alternate to other woods rather than a cheap substitute. The attitude of prospective buyers of alder will improve as the local industry improves delivery, quality control, and promotional efforts." (A)

37. Bene, John.

1950. Douglas fir substitutes for the British Columbia plywood industry. B.C. Lumberman 34(8):49-50, 145.

"This paper...discusses the possibility of using Hemlock and Cedar and other conifers, tropical harwoods, and, in more detail, some West Coast hardwoods (Populus trichocarpa, Betula papyrifera var. occidentalis, Acer macrophyllum and Alnus rubra) for plywood. The importance of hardwoods in the veneer industry is emphasized. (FA)

38. Berg, Alan, and Allan Doerksen.

1975. Natural fertilization of a heavily thinned Douglas-fir stand by understory red alder. For. Res. Lab. Res. Note 56, 3 p. Oreg. State Univ., Corvallis.

"Describes the natural establishment of Alnus rubra under a 62-year-old Pseudotsuga menziesii stand in Oregon after a heavy thinning in 1955. Growth of the A. rubra understorey was rapid, but examination in 1972 showed that the overstorey canopy was closing and many of the understorey trees were dead. Soil analyses showed that a dense understorey of A. rubra added ca. 780 lb total N/acre in the top 6 inches. It is suggested that A. rubra could be introduced either naturally or artificially to increase the N content of the soil in similar conditions." (FA)

39. Berg, Alan B., ed.  
1972. Managing young forests in the Douglas-fir region. Vol. 3. Sch. For. Pap. 734, 224 p. Oreg. State Univ., Corvallis.

"These printed proceedings include 8 tech. repts. by different authors, descriptions of several field trips (to pulp and lumber cos., govt. forestry agencies, and the Willamette Natl. Forest), a banquet address on foresters' relations with the public and a final discn. session on the management of young timber stands. The tech. presentations dealt with management of Douglas-fir in Europe, the role of alder in improving soil fertility and growth of assocd. trees, regulation of soil organisms (control of Poria weiri) by red alder, economics and marketing of alder, admin. of thinning contracts and of partial-cut sales, econ. guides for intensive forest management, and foresters' approaches to the marking of trees for thinning. A good subject index is appended." (FA)

40. Bergman, Stuart I.  
1949. Lengths of hardwood fibers and vessel segments: A statistical analysis of 49 hardwoods indigenous to the United States. Tappi 32(11):494-498.

"Up to 4 samples of each of 49 indigenous hardwoods were macerated and the lengths of fibres and vessel segments were measured. The results were tabulated, the woods being classified according to fibre and vessel-segment length. The results show that: (1) the difference between average lengths of fibre and vessel segments of 2 samples of the same species may be greater than the corresponding differences for 2 samples from different species; (2) wider sampling is necessary before a mean and standard deviation for

lengths in a particular species can be obtained--samples from different parts of the same tree and from trees from varying sites and districts would be needed; (3) there is a high degree of positive correlation between the lengths of the fibres and those of the vessel segments." (FA)

41. Berntsen, Carl M.  
1954. Some results of chemical de-barking on Sitka spruce, western hemlock, and red alder. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 104, 7 p. Portland, Oreg.

"Out of 4 chemicals brushed on to b.h. band girdles in July-August, only undiluted Na arsenite gave 100% kill for Sitka and Hemlock (100 years old) within 2 months, bark being readily removable (except below the girdle) within 1 year. Alder bark, however, often remained tight. A basal spray of Alder with 2,4-D and 2,4,5-T (2%) in diesel oil killed several 30-year-old trees in 2 years and the others appeared to be dying." (FA)

42. Berntsen, Carl M.  
1958. A look at red alder--pure, and in mixture with conifers. Soc. Am. For. Proc. 1958:157-158.

"Reports on test plots established in 1935-37 in mixed stands aged 8-12 years. In the control plots (1) there were ca. 3000 stems/acre; (2) was thinned to 2000 stems, and (3) to 733 stems/acre of pure Alder, and (4) to 1148 stems/acre of pure conifers (Sitka Spruce, Douglas Fir, and Western Hemlock). At 30 years, volumes and c.a.i. (in bd. ft.) were respectively: 2900 and 260 for (1), ca. 3300 and 260 for (2) and (3), and 4300 and 400 for (4)." (FA)

43. Berntsen, Carl M.

1961. Growth and development of red alder compared with conifers in 30-year-old stands. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Pap. 38, 20 p. Portland, Oreg.

Treatments were as follows: (1) pure alder, unthinned; (2) mixed alder-conifer, unthinned; (3) pure alder, thinned from an alder-conifer stand at age 11 years; and (4) pure conifer, thinned from an alder-conifer stand at age 8. Major results were: By age 29 years, the slow-starting pure conifer stand had about equaled the volume of the 32-year-old, unthinned, pure alder stand and had surpassed the yield of the thinned, pure alder and unthinned alder-conifer stands. Yield of the thinned, pure alder stand at age 31 was about 13 percent less than that of the unthinned, pure alder stand. Yield of the unthinned alder-conifer stand at age 29 was the lowest of all the experimental stands. (CFH)

44. Berntsen, Carl M.

1961. Pruning and epicormic branching in red alder. J. For. 59(9):675-676.

"Dissected trunk sections showed that pruning scars on trunks of red alder trees (Alnus rubra) healed rapidly, but formation of clear wood was limited by development of epicormic branches. Bud strands, originating in the leaf axil on the main stem elongated radially with each annual layer of wood. Bud-producing tissues at the terminal point of these strands gave rise to epicormic branch development in response to a certain physiological release triggered by the pruning treatment." (FA)

45. Berntsen, Carl M.

1962. A 20-year growth record for three stands of red alder. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 219, 9 p. Portland, Oreg.

"Compares with yield-table data the growth between the 21st and 41st years of natural stand viz. (a) two stands released from a light overstorey of Douglas Fir (by girdling), one only of which was then thinned, and (b) a pure Alder stand unthinned. The volume of (b)--4423 cu. ft./acre--at year 41 exceeded that of the tables. Thinning did not stimulate growth and it is considered that natural thinning could be relied upon in this intolerant species." (FA)

46. Besley, L.

1966. Importance, variation, and measurement of wood density and moisture. Woodland Res. Index Pulp and Pap. Res. Inst. Can. 182, 30 p.

"Reviews, in relation to the substitution of weight measurement for volume determination, some of the world literature on variation in wood density (w.d.) and moisture content (m.c.) found in pulpwood as delivered to mills, and as occurring between forest stands, trees species, individual trees of the same species, and various positions in the same tree. Values for 30 softwoods and 23 hardwoods, as reported by several investigators, are tabulated, including differences up the tree and radially, at the same height, across the sapwood and heartwood, and across the early and late wood of individual growth rings. The effects of season on m.c. in the standing tree, and of time since cutting on m.c. in the harvested tree or pulpwood, are also reported. Some methods and instruments now in use for measuring w.d. and m.c. are briefly discussed. Finally, a suggestion

is made for direct conversion, on a periodic basis, of the wet weight of rough wood to its oven-dry equivalent in usable wood fibre, using the average ratios for different seasons in the year, and different drying periods, obtained from tests on sample disks, and thus avoiding the intermediate steps of separately determining bark weight, and basic density and m.c. of the wood." (FA)

47. Betts, H. S.  
1960. American woods red alder.  
Am. Woods, 4 p. USDA For. Serv.  
Washington, D.C.

"Distribution and growth, supply, production, properties and uses of the following: ... Alnus rubra ..." (FA)

48. Bishop, Daniel M., Floyd A. Johnson, and George R. Staebler.  
1958. Site curves for red alder.  
USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 162, 7 p. Portland, Oreg.

"This preliminary report presents site-class curves (60 to 120 ft. by 20-ft. classes) for Alnus rubra, developed during yield-table construction and based on stem analyses of 43 trees from a representative spread of site conditions in W. Washington." (FA)

49. Bodig, J.  
1965. The effect of anatomy on the initial stress-strain relationship in transverse compression. For. Prod. J. 15(5):197-202.

"Continuously recorded stress-strain curves and photographs taken simultaneously at different stages of compression of four species of different anatomical characteristics demonstrated the importance of anatomy and direction of loading in the determination of the stress-strain relationship of wood in transverse compression. Explanations and theories are given for the mechanisms of failures in radial and tangential compression, for the presence or absence of maximum stress points, and for the initial curvature of the stress-strain curves. The weak layer theory in radial compression and the spaced column behavior in tangential compression has been discussed and illustrated." (A)

50. Bollen, W. B., C. S. Chen, K. C. Lu, and Robert F. Tarrant.  
1968. Effect of stemflow precipitation on chemical and microbiological soil properties beneath a single alder tree. In Biology of alder, p. 149-156. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Stemflow from a red alder tree had a substantially greater concentration of nitrogen and dissolved solids and slightly lower pH than gross rainfall. On a weight/area basis, however, the contribution of nutrient ions in stemflow was very small compared to that in gross rainfall or throughfall. No evidence was

found to indicate that enriched stemflow affected chemical and microbial properties of soil at a distance of only 2 feet from the stem. Results of this study support previous demonstration of a narrow absorption area about the tree stem as the total soil area affected by stemflow." (A)

51. Bollen, W. B., and K. C. Lu.  
1957. Effect of Douglas-fir sawdust mulches and incorporations on soil microbial activities and plant growth. *Soil Sci. Soc. Am. Proc.* 21(1):35-41.

"Gives data on the decomposition rate, measured by  $\text{CO}_2$  production in soil respiration tests, and other chemical data, including C/N ratios, for various organic materials used as mulches and fertilizers, relative figures for decomposition in one test being: wheat-straw 48, sawdust of Red Alder 40, of Ponderosa Pine, and Western Red Cedar 33, of Douglas Fir 30 and of Western Hemlock 27, Douglas Fir resin 30, and Douglas Fir bark, 26. Added N hastened decomposition of substances with a high C/N ratio, though it generally depressed cumulative evolution of  $\text{CO}_2$ .

"Owing to its low content in both N and available C, resulting in slow decomposition, Douglas Fir sawdust has a less depressive effect on plant growth through induced N deficiency than was commonly found in substances with high C/N ratios. At 10 tons/acre, it significantly increased first crop yields, though at 100 tons (a 5-in. layer) it depressed them. Ponderosa pine sawdust and Douglas Fir bark at 10 tons/acre depressed yields, but added N produced increases over untreated crops in all cases." (FA)

52. Bollen, W. B., and K. C. Lu.  
1968. Nitrogen transformations in soils beneath red alder and conifers. In *Biology of alder*, p. 141-148. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Transformations of nitrogen in organic matter in the soil are essential to plant nutrition because nitrogen in the form of proteins and other organic compounds is not directly available. These compounds must undergo microbial decomposition to liberate nitrogen as ammonium ( $\text{NH}_4^+$ ) and nitrate ( $\text{NO}_3^-$ ), which can then be absorbed by plant roots.

"Nitrogen transformations, particularly nitrification, are rapid in soils under coastal Oregon stands of red alder (*Alnus rubra* Bong.); conifers--Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.); and mixed stands of alder and conifers. Nitrification is especially rapid in the F layer beneath alder stands despite a very low pH. These findings are from a study of contributions to the nitrogen economy by red alder conducted at Cascade Head Experimental Forest near Otis, Oregon." (A)

53. Bollen, W. B., and E. Wright.  
1961. Microbes and nitrates in soils from virgin and young-growth forests (east and west of the Cascade Mountains and along the U.S. Pacific coast). *Can. J. Microbiol.* 7(5):785-792.

"Penicillium spp. predominated in samples of forest soils, except occasionally at depths of > 3 in., when Mucor and Aspergillus spp. were sometimes more abundant. Incubation for 30 days at 28° C and 50% moisture capacity frequently increased the % of Mucor as well as of Penicillium spp. Mucor spp. were consistently more predominant in soils associated with Alder than in other coastal soils. Mucor and Aspergillus spp. also appeared often in soil from stands of Ponderosa Pine growing E. of the Cascades. The greatest concentration of N as NO<sub>3</sub> in unincubated soils was found in a young Red Alder stand. Samples of soil from stands of virgin coastal Redwood showed no NO<sub>3</sub>-N. Soils from stands of virgin Sitka Spruce, however, showed considerable NO<sub>3</sub> content, which increased markedly with incubation. With few exceptions, bacteria and actinomycetes were most numerous in the F soil horizon. Incubation greatly increased these populations in most soils." (FA)

54. Bollen, Walter B.  
1953. Mulches and soil conditioners: Carbon and nitrogen in farm and forest products. *J. Agric. and Food Chem.* 1(5):379-381.

"The nitrogen content of organic matter used as mulches or soil conditioners not only influences rate and extent of their decomposition and humidification but also determines the available nitrogen released or required. Data on the carbon-nitrogen ratio of such materials are therefore essential for decomposition

studies and for predicting additional nitrogen requirements for optimum microbial activity. Carbon-nitrogen values are also indicative of B.O.D. and pollutional potentials of organic wastes dumped into streams. Carbon-nitrogen values were determined for 55 agricultural and forest wastes used on soils in the Pacific Northwest. All coniferous wood wastes are similar in containing approximately 50% carbon and little nitrogen. Hay and straw average 45% carbon and also are low in nitrogen. Young plants and leguminous materials are higher in nitrogen, decompose readily, and liberate nitrogen in available form. Wood, straw, and similar residues of wide carbon-nitrogen ratio decompose slowly, demanding available nitrogen in inverse proportion to resistant components. With much lignocellulose and little water-soluble substance present, the carbon-nitrogen ratio is of secondary importance in controlling microbial decomposition." (A)

55. Bollen, Walter B., Chi-Sin Chen, Kuo C. Lu, and Robert F. Tarrant.  
1967. Influence of red alder on fertility of forest soil: Microbial and chemical effects. *Oreg. For. Res. Lab. Res. Bull.* 12, 6 p. Oreg. State Univ., Corvallis.

"A detailed study of ways in which Alnus rubra contributes to the fertility of a forest soil. Microbial and chemical characteristics of the soil were determined at seasonal intervals from April 1962 to March 1963 in stands of (a) pure Alder, (b) pure conifers and (c) an Alder/conifer mixture, in Cascade Head Experimental Forest on the Oregon coast. Moulds were more numerous in the F layers than in the A1l horizon, and usually lowest under (b). Numbers of bacteria (including Streptomyces spp.) were high under (b) and low under (c), with peaks

in September in the F layers of (a) and (b); changes under (c) were mostly small. Streptomyces spp. (which produce antibiotics) were most prominent under (c) at all seasons; attention is drawn to the possible importance of this in relation to inhibition of fungal pathogens on conifer roots. The lowest pH values were usually found in soils under (a), and the highest in the F layer under (b). The pH of All horizons was generally higher than that of F layers and more variable seasonally, the highest values being recorded in July. Nitrate N and acidity were always higher under (c) than (b), indicating the greater probability of inhibition of root-rots and soil-borne diseases in (c). Exchangeable Ca was less abundant in soil under (a) and (c) than under (b). More litter, with a narrower C/N ratio, was contributed by (a), partly because of an abundant understorey. N transformations were vigorous in all the soils; total N was greater under (a) and (c) than under (b). A brief survey of the literature is given in the appendix." (FA)

56. Bond, G.

1955. An isotopic study on the fixation of nitrogen associated with nodulated plants of Alnus, Myrica, and Hippophae. J. Exp. Bot. 6(17):303-311.

57. Bond, G.

1956. Evidence for fixation of nitrogen by root nodules of alder (Alnus) under field conditions. New Phytol. 55(2):147-153.

Describes apparatus for determining N fixation of intact Alnus glutinosa root nodules in the field. Results show that field root nodules regularly fix nitrogen. (CFH)

58. Bond, G.

1964. Isotopic investigations of nitrogen fixation in non-legume root nodules. Nature, Lond. 204(4958):600-601.

"Earlier experiments showed that when 10% of N is present in the supplied atmosphere (total pressure 1 atm) fixation is detached nodules of Alnus, Casuarina, Myrica, and Hippophae is depressed if the % of O is > 20. In a further experiment with Casuarina nodules, the extent of this inhibition by O in the presence of increased gaseous N was investigated. Results with 10% N were similar to those already reported. With 30% N, the inhibitory effect of increasing O tension was considerably mitigated. This could be explained by competition between O and N at some stage in the fixation process. Other aspects under investigation are the N-fixing capacity of excised and of homogenized nodules, and the path of translocation of fixed N in the nodulated plant (it is tentatively suggested that this normally occurs through the xylem, at least in Alnus and Hippophae)."  
(FA)

59. Bond, G.

1967. Fixation of nitrogen by higher plants other than legumes. Ann. Rev. Plant Physiol. 18:107-126.

Review of the taxonomy, cytology, and ecology of nitrogen-fixing root endophytes. Discusses practical and ecological aspects. Has separate sections on mycorrhizal plants and leaf bacteria.  
(CFH)

60. Bond, G.  
1970. Fixation of nitrogen in non-legumes with Alnus-type root nodules. In Nitrogen nutrition of the plant, p. 1-8. E. A. Kirby, ed. Agric. Chem. Symp. Leeds 2. Waverly Press, Leeds Univ., England.
- "Casuarina, Elaeagnus and other angiosperms possess root nodules inhabited either by Rhizobium or filamentous bacteria, these nodule types showing many physiological and biological resemblances. The N-fixing non-legumes, e.g. Alnus jorullensis, Dryas drummondii and Myrica cordifolia, are considered to be of great ecological and economic importance in providing N in regions occupied by natural vegetation." (FA)
61. Bond, G.  
1971. Root-nodule formation in non-leguminous angiosperms. Plant and Soil Spec. Vol. 1971:317-324.
- "Investigations in progress, as part of the IBP, have confirmed or established the fixation of N by a number of non-leguminous species, including Alnus jorullensis, Myrica cordifolia, and M. pilulifera. Information is given on diurnal variations in the rates of N fixation of some non-legumes, with the results of analyses of the amino-acid composition of the nodules." (FA)
62. Bond, G.  
1974. Root-nodule symbioses with actinomycete-like organisms. In The biology of nitrogen fixation, p. 342-378. A. Quispel, ed. North-Holland Publ. Co., Amsterdam.
- Red alder is among the species discussed in relation to nitrogen fixation by root nodule endophytes. (CFH)
63. Bond, G.  
1976. The results of the IBP survey of root-nodule formation in non-leguminous angiosperms. In Symbiotic nitrogen fixation in plants, p. 443-474. P. S. Nutman, ed. Cambridge Univ. Press, England.
- Lists species of Alnus and other non-leguminous genera found to have root nodules in a worldwide survey in 1967. (CFH)
64. Bond, G., W. W. Fletcher, and T. P. Ferguson.  
1954. The development and function of the root nodules of Alnus, Myrica, and Hippophae. Plant and Soil 5:309-323.
- Report of work with Alnus glutinosa. In alnus, the optimum pH for growth of nodulated plants is lower than for nodule initiation. The effect of ammonium-nitrogen in the culture solution was to increase plant and nodule development, but the ratio of nodule weight to plant weight was decreased. (CFH)

65. Bongard, Heinrich Gustav.  
 1833. Observations sur la végétation de l'ile de Sitcha. Akad. Sci. St. Petersb. Mem. Sci. Math. Phys. Nat. Ser. 6 II:119-177.
- The original description of red alder as a species. (CFH)
66. Borden, J. H., and W. F. Dean.  
 1971. Observations on Eriocampa ovata L. (Hymenoptera: Tenthredinidae) infesting red alder in southwestern British Columbia. J. Entomol. Soc. B. C. 68:26-28.
- "Observations on the biology of Eriocampa ovata (L.) on Alnus rubra in British Columbia indicated that in this province, as in Quebec, the species is bivoltine and parthenogenetic and overwinters as a prepupa. In British Columbia, the first-instar larvae were found to emerge on the lower sides of the leaves and to pass through 6-7 instars rather than the 5-6 recorded in Quebec. It was noted that defoliation of the tree characteristically left only the midrib and main secondary veins and that in limited areas small trees might be completely defoliated." (EO)
67. Bornebusch, C. H.  
 1943. H. Forskellige Bladarters Forhold til Omsætningen i Skovjord. [The influence of leaves of different species on decomposition in the forest soil.] (Abstr.) Forstl. Forsgsvaesen Dan. 16:265-272. [In Danish. German summary.]
68. Brackett, Michael.  
 1973. Notes on tarif tree volume computation. State Wash. Dep. Resour. Resour. Manage. Rep. 24, 26 p. Olympia, Wash.
69. Bramhall, G., Compiler.  
 1966. Wood marine piling symposium. II. Transcript of symposium held at the University of British Columbia on May 30, 1966. For. Prod. Lab. Inf. Rep. VP-X-9, 108 p. Vancouver, B. C.
- "A collection of 9 papers, with discussion on each, comprising: Marine borers in B.C. coastal waters ...; Procurement and treatment of marine piling ...; Effect of incising on penetration of creosote in Western Hemlock piles ...; A comparison of the assay and multiple boring methods of inspecting Douglas Fir marine piling ...; Marine exposure tests of pressure-treated Douglas Fir and Southern Pine ...; Combination treatments for marine piles ...; Immersion studies on copper chrome arsenate (Boliden K-33 salts) in Pacific coast waters ... [tabulates and discusses results (generally promising) of trials of timber and poles of Alnus sp., ... at different localities along the coast]; Leaching rates and threshold values of wood preservatives in marine exposure blocks ...; and Problems and techniques in pile driving ..." (FA)
70. Brayshaw, T. C.  
 1960. Key to the native trees of Canada. Can. Dep. For. Bull. 125, 43 p.
- "Includes (1) general key to the trees, (2) general key to deciduous trees in winter, (3) separate keys to the genera ... Alnus ... ." (FA)

71. Brayshaw, T. C.  
1976. Catkin bearing plants  
(Amentiferae) of British Columbia.  
Occas. Pap. B. C. Prov. Mus. 18,  
176 p. Victoria, B. C.
72. Briggs, David G., and James S.  
Bethel.  
1978. The potential for integrated  
utilization of alder. In Utilization  
and management of alder, p. 163-173.  
David G. Briggs, Dean S. DeBell, and  
William A. Atkinson, compilers. USDA  
For. Serv. Gen. Tech. Rep. PNW-70.  
Pac. Northwest For. and Range Exp.  
Stn., Portland, Oreg.

"In attempting to evaluate utilization possibilities from forest stands, we are often confronted with an array of data that is either in the wrong units of measurement or has inappropriate utilization assumptions built in. Ecologists can often provide biomass data; but this is usually expressed in terms of total weights of crowns, stems, and roots with little regard to components useful to man. The foresters' tools are log rules, volume tables, and yield tables; but these are of limited value because they often incorporate fixed and somewhat arbitrary assumptions concerning product mix and manufacturing parameters.

"What is needed is a method that views the stand in terms of its basic units, the trees, and on the basis of the sizes and shapes of trees can apply relevant manufacturing requirements to obtain estimates of product output. Such an approach is described and illustrated where an alder stand is being considered for conventional sawlogs and pulp, logs SHOLO and pulp, and a mixture of the two." (A)

73. Briggs, David G., James S. Bethel,  
and Gerard F. Schreuder.  
1978. An approach for comparing the  
relative value of alder with other  
species from forest to end product.  
In Utilization and management of  
alder, p. 35-46. David G. Briggs,  
Dean S. DeBell, and W. A. Atkinson,  
compilers. USDA For. Serv. Gen.  
Tech. Rep. PNW-70. Pac. Northwest  
For. and Range Exp. Stn., Portland,  
Oreg.

"Comparing alder as a renewable species with other species depends on a thorough analysis of a variety of technical and economic data from the system for growing trees through their end use. All too frequently, detail and components of the system are overlooked in policy analysis because a consistent and comprehensive format of appropriate data is not available.

"What is needed is a framework that incorporates diverse information on the technical, economic, labor, energy, and environmental aspects of production systems, captures those characteristics important to policy decisions, and thus facilitates the study of the role of alder as a source of materials in comparison to competing alternatives.

"This paper explains the Reference Materials System (RMS) adapted by the National Academy of Sciences' Committee on Renewable Resources for Industrial Materials. RMS is suggested for use in examining the complex issues concerning alder management and utilization." (A)

74. Briggs, David G., Dean S. DeBell, and William A. Atkinson, Compilers. 1978. Utilization and management of alder. USDA For. Serv. Gen. Tech. Rep. PNW-70, 379 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Proceedings of a symposium held at Ocean Shores, Washington, April 25-27, 1977. Contributors are cited elsewhere in this bibliography. (CFH)

75. Brill, Winston J. 1977. Biological nitrogen fixation. Sci. Am. 236(3):68-81.

A popular account of the biology and chemistry of nitrogen fixation. (CFH)

76. British Columbia Department of Lands and Forests. 1953. Chemical treatment of standing trees as a method of debarking. In Report of the Forest Service 1952, p. 38-39. Victoria, B.C.

" $\text{Na}_2\text{HAsO}_3$  killed Tsuga heterophylla and Alnus rubra more quickly and easily than  $\text{NH}_4$  sulphamate. Only Alder was killed by Esteron (2,4,5-T). Douglas Fir did not respond well to any of these chemicals. Loosening of the bark on the whole stem was found only on T. heterophylla after treatment with arsenite." (FA)

77. British Columbia Forest Service. 1947. Yield tables. 3d print. p. 42-43. Victoria B.C.

78. Brix, H. 1966. Errors in measurement of leaf water potential of some woody plants with the Schardakow dye method. Dep. For. Can. Publ. 1164, 11 p. Ottawa.

"The Schardakow dye method gives too low estimates of leaf water potentials for Douglas-fir, bigleaf maple, and red alder. The total error could amount to -12.5, -6.5, and -5.0 atmospheres for turgid leaves of the three plants respectively. Contamination of test solutions from cut cells is the major source of error, but solute uptake by the leaves from the test solutions contributes to the total error. By excluding the concentration changes occurring during the first one-half hour of tissue equilibration the total error could be reduced to -7.5, -2.4, and -1.6 atmospheres for the three plants. The error is most likely smaller for leaves having a lower water potential." (A)

79. Brockman, C. Frank. 1959. Red alder (Alnus rubra Bong.). Arbor. Bull. 22(2):50-51, 59. Arbor. Found., Seattle, Wash.

80. Brough, Sherman G. 1974. Tremella globospora, in the field and in culture. Can. J. Bot. 52(8):1853-1860.

"Tremella globospora Reid is described from 32 collections made in British Columbia. The fungus grows directly from within perithecia of species of Valsa and Diaporthe found, in this study, on hosts belonging to seven Angiosperm genera and three of Gymnosperm. Single-spore isolates were made from basidiocarps selected to represent as many variables as

possible; both colors (yellow and white) of the basidiocarp, proximity of position on a single twig versus considerable distance between sites, both genera of pyrenomycete host, four genera of seed plants, and collection dates from January to September. Compatibility tests indicated a single species with a modified tetrapolar mating system typical of the genus Tremella. Selected dikaryotic isolates were grown in laboratory culture on simple media, and fertile basidiocarps were produced. Variation in size, color, and consistency of basidiocarps in culture was compared with those in field collections. Clamp connections, branching from the clamp cell, and other microstructures produced in culture are also described. No reaction of T. globospora to Valsa cultures or sterilized Valsa perithecia and extracts was observed." (A)

81. Brown, George W., and James T. Krygier.  
1971. Clear-cut logging and sediment production in the Oregon Coast Range. Water Resour. Res. 7(5):1189-1198.

"Reports results of an 11-year study in three small catchments with Douglas Fir/Alder forest cover to determine the effect of road construction, clear felling and logging, and slash burning on sediment production. Road construction and slash burning caused substantial increases in sediment production during a 4-year period, whereas felling and yarding did not. Conclusions about the significance of all except very large changes in sediment production are limited because of annual variations within the between catchments." (FA)

82. Brown, K. J., and J. N. McGovern.  
1953 High-yield cold soda pulps and products from several woods. Pap. Ind. 35(1):66-69.

"Hardwoods such as aspen (I), birch (II), red alder (III), sweet gum (IV), cottonwood (V), red (VI) and white oak (VII) and mixts. of III and VI or VII could be pulped by the 'cold soda process' (VIII) which entails steeping 1.5-2 hrs. at atm. pressure and room temp. with solns. contg. 20-100 g. NaOH/l., resulting in chem. consumption of 5-8% (on the dry-wood basis). Some hemicelluloses are lost, but there is little if any loss in lignin or  $\alpha$ -cellulose. The softened chips are fiberized in an attrition mill. Yields range from 88 to 90% and the resulting pulps could be bleached satisfactorily to a brightness of 65-70%. Bleached pulps from I were apparently suitable for use in printing papers of the groundwood type (but further printing tests are required). Corrugating boards with high flat-crush-resistance could be made from I, III, and IV. At the same yield, I, II, III, and V pulps are stronger than those from IV, VI, and VII. Within limits of the process, the pulp strength increases with decreasing yield. The strength also increases as the pulps are processed to lower freeness. Bark adversely affects VIII and lowers pulp and board quality. Softwoods (like jack pine and hemlock) are not satisfactorily pulped by VIII." (FA)

83. Browne, F. G.  
1968. Pests and diseases of forest plantation trees. 1,330 p. Clarendon Press, Oxford.

Browne comprehensively describes animal pests, pathogenic viruses, bacteria, fungi, and higher plants found on forest plantation trees throughout the British Commonwealth. Species listing provides cross-reference to pests. No general index. Extensive bibliography. (CFH)

84. Browne, J. E.  
1962. Standard cubic-foot volume tables for the commercial tree species of British Columbia, 1962. 107 p. B.C. For. Serv. For. Surv. and Inventory Div., Victoria, B.C.
85. Bruce, David, Robert O. Curtis, and Caryanne VanCoevering.  
1968. Development of a system of taper and volume tables for red alder. For. Sci. 14(3):339-350.
- "An estimating equation was derived for red alder (Alnus rubra Bong.), expressing ratio of squared upper stem d.i.b. to squared dbh outside bark as a function of dbh, total height, and the 3/2, 3rd, 32nd, and 40th powers of relative height. This equation formed the basis for a system of tables and equations which provides estimates of tree volume for various combinations of product units, utilization limits, and size classes of material. The methods used should also be applicable to other species." (A)
86. Bryant, Ben S., and Judson Wonderly.  
1964. An economic analysis of the hardwood industry of western Washington. 101 p. Inst. For. Prod., Univ. Wash., Seattle, and Bus. and Econ. Res. Div., Wash. State Dep. Commer. and Econ. Dev., Olympia.
- A reprint of the master's thesis submitted by John H. Grovey (208). Discusses history and growth of hardwood lumber industry of western Washington. Includes various statistics on consumption prices and harvests. Compares physical properties and uses of Northwest hardwoods. (CFH)
87. Bublitz, Walter J., and Tommy D. Farr.  
1971. Pulping characteristics of bigleaf maple (Acer macrophyllum Pursh.). Tappi 54(10):1716-1720.
- "Bigleaf maple is a hardwood that grows prolifically in the coast range of the Pacific Northwest, and there is an estimated 3 billion board feet of this species growing in Oregon alone. The pulpwood potential of this species was investigated for four processes: kraft, Magnefite, semichemical, and refiner groundwood. Bleaching trials were conducted on the kraft, Magnefite, and ground wood pulps. Suitable quality unbleached pulps can be made in good yields by the kraft and Magnefite processes, and these pulps may be readily bleached to 70-80% brightness by standard bleaching techniques. With the exception of the refiner groundwood pulp, the strength properties of the bleached and unbleached pulps compare quite favorably with those of other hardwood market pulps. The refiner groundwood is weak and has low scattering power. The Concordia crushing strength of NSSC pulp, however, is exceptionally high for the high yield of that pulp, which suggests that bigleaf maple would make an outstanding corrugating medium pulp." [Tabular comparison with strength properties of other species including red alder.] (A)
88. Calder, J. A., and Roy L. Taylor  
1968. Flora of the Queen Charlotte Islands. Part 1. Systematics of the vascular plants. Can. Dep. Agric. Mon. 4, 658 p. Ottawa.
- Ecology and distribution of red alder in the Queen Charlotte Islands is given. There also is an extensive discussion of botanical history, physiography, geology, climate, and plant communities. (CFH)

89. Calder, J. A., and Roy L. Taylor. 1968. Flora of the Queen Charlotte Islands. Part 2. Cytological aspects of the vascular plants. Can. Dep. Agric. Mon. 4, 148 p. Ottawa.
- Chromosome number of five collections of red alder are reported as  $2n=28$ . Methods and materials section describes field collection and laboratory determination of chromosome number. (CFH)
90. Callier, A. 1892. Über die in Schlesien vorkommenden Formen der Gattung Alnus. Jahresber. der Schlesischen Ges. für Vaterl. Cult. 69(2):72-85.
91. Callier, A. 1904. Gattung Alnus. In Illustriertes Handbuch der Laubholzkunde Jena. C. K. Schneider, ed. Vol. 1, p. 119-136; Vol 2, p. 857-891.
92. Callier, A. 1911. Diagnoses formarum novarum generis Alnus. Fedde Repert. Spercierum Nov. Regni Veg. 248/250, X. Band, p. 225-237.
93. Callier, A. 1918. Alnus Formen der europäischen Herbarien und Garten. Mitt. Dtsch. Dendrol. Ges. 27:38-185.
94. Cameron, P. J., and W. G. Wellington. 1975. Effects of the plant growth regulator indolebutyric acid on the growth, development, and reproduction of the western tent caterpillar, Malacosoma californicum pluviale (Lepidoptera: Lasiocampidae). Can. Entomol. 107(12):1339-1342.
- "In laboratory experiments in British Columbia, the synthetic plant-growth regulator indolebutyric acid added at 0.1 g/litre to the water in which was kept cut foliage of red alder (Alnus rubra) on which larvae of Malacosoma californicum pluviale (Dyar) were reared delayed pupation, caused a reduction in the weight of the pupae, and hindered the last larval moult. Larvae fed on treated foliage when very young gave rise to adults that produced more eggs and a higher proportion of viable ones than the untreated controls. Treatment of older larvae produced antigenotoxic effects." (EO)
95. Carstensen, John P. 1961. Gluing characteristics of softwood veneers and secondary western hardwoods. For. Prod. J. 11(7):313-315.
- "Discusses the modifications in formulations and techniques necessary when using protein or synthetic resin glues, normally formulated for Douglas-fir, for Western Pines, Sequoia, Western Red Cedar, Western Hemlock, Western Larch, Sitka Spruce, true Firs, Red Alder, Pacific Madrone and Tan Oak." (FA)

96. Chamberlain, Charles T.

1927. Observations on the treatment of hay fever in the Pacific Northwest: Fifty-three cases. Ann. Otol. Rhinol. Laryngol. 36:1083-1092.

"1. Approximately 95 per cent of all hay fever in Oregon is of the early or midsummer type, caused by the pollens of the grasses.

"2. The cutaneous or scratch method of testing patients for their pollen reactions is satisfactory if performed carefully and with uniform technic.

"3. The glycerin saturated sodium chlorid solution method of extracting pollens gives a more potent preparation, both for testing and for treatment, than the 12 per cent alcoholic normal saline extract.

4. More intensive treatment by use of more potent pollen extracts, giving of more frequent doses, and a larger final dose, gives better end results in hay fever treatments.

5. The combining of several pollens, especially is from different groups of plants, in a treatment preparation is not advisable, and may be a factor in failure to secure satisfactory results in some cases.

6. A thorough survey of the botanical flora of a locality must be made, and the hay fever plants, with their distribution and dates of pollination known, before one can hope to obtain the best possible results in hay fever work." (A)

97. Chambers, Charles J.

1974. Empirical yield tables for predominantly alder stands in western Washington. Wash. State Dep. Nat. Resour. DNR Rep. 31, 70 p. Olympia, Wash.

"Yield tables based on 174 permanent points located in Western Washington were

developed for pure hardwood and mixed hardwood-conifer stands, using total age and 50-year site index curves. Density expressed as percent normal basal area (PNBA) was added to increase accuracy. It was concluded that there was no significant difference in cubic volume, top and stump (CVTS) between pure hardwood and mixed harwood-conifer stands on DNR lands in Western Washington. Pure, even-aged hardwood stand and stock tables, with volume by log position by DBH classes, were constructed, based on 36 hardwood points. Hardwood stands in this report are assumed to be predominantly alder stands." (A)

98. Chang, Ying-Pe, and Raymond L. Mitchell.

1955. Chemical composition of common North American pulpwood barks. Tappi 38(5):315-320.

"Components determined in 9 softwood and 15 hardwood barks were as follows: ash, extractives, 'lignin', methoxyl in 'lignin' and bark, and the amount and composition of the reducing sugars produced from extractive-free bark by 72% H<sub>2</sub>SO<sub>4</sub>. The hot-water extract was tested qualitatively for tannins by two methods. Solubility of bark in 1% NaOH and the amount of precipitate obtained by acidifying the alkaline extract were also determined. Heat of combustion values were measured for 8 softwood and 12 hardwood barks. Most of the barks contain relatively large amounts of ash, extractives, 'lignin' and material soluble in 1% NaOH. The high solubility in alkali, exceeding 50% for seven barks, suggests a potential means for utilizing these barks. Apparent trends in the relation of chemical composition to physical structure of bark are discussed briefly." (A)

99. Chen, Chi-Sin.  
1965. Influence of interplanted and pure stands of red alder (Alnus rubra Bong.) on microbial and chemical characteristics of a coastal forest soil in the Douglas-fir region. Ph. D. thesis. Oreg. State Univ., Corvallis. 164 p.

"Gives the results of a study on the distribution of moulds and bacteria, pH values, contents of N, sulphate, phosphate, and exchangeable H and cations, the degree of ammonification and nitrification, and the S-oxidizing power in the various horizons of soils under Alder, conifers, and mixed Alders and conifers, and the dry matter, NH<sub>4</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup> and Kjeldahl N in canopy rainfall and stem flow." (FA)

100. Cheng, Chi Shan.  
1949. The soaking treatment of black cottonwood and red alder fence posts in pentachlorophenol. J. For. 47(8):651-652.

"A report on investigations into cold- and hot-soaking preservative treatments of seasoned Black Cottonwood [Populus trichocarpa] and Red Alder [Alnus rubra]. Round posts can be successfully treated by soaking in unheated 5% pentachlorophenol/diesel-oil solution, so long as the depth of the solution is not less than the height of treatment desired. Incising the posts doubled the depth of radial penetration in Red Alder and increased it by about 10% in Black Cottonwood. A reduction in retention is possible in incised posts of these species because the uniform radial penetration obtained makes it unnecessary to rely on end penetration. No significant difference could be found between hot and cold-soaking." (FA)

101. Chow, S.  
1972. Thermal reactions and industrial uses of bark. Wood and Fiber 4(3):130-138.

"Demonstrates that phenols in Douglas Fir and Red Alder bark can be polymerized at temperatures above 200 deg. C. and describes how this reaction can be used to advantage in the production of material with high oil absorption (useful e.g. for cleaning up oil spills), or adhesive-free bark chipboards.

"Boards made in this way were equal in internal bond strength and bending strength to, and greater in dimensional stability than, corresponding bark boards manufactured at lower temperatures and containing 4.5% PF adhesives." (FA)

102. Chow, S., and K. J. Pickles.  
1971. Thermal softening and degradation of wood and bark. Wood and Fiber 3(3):166-178.

"The thermal softening of powdered wood and bark of Pseudotsuga menziesii and Alnus rubra was studied over a range of moisture contents. Softening of oven-dry samples begins at 180° C and ends at about 500° C, with a maximum rate of softening at 380°C. An increase in m.c. lowers the softening temperature owing to plasticization by moisture. The reactions occurring when wood and bark are heated above 180° C were shown by differential thermal analysis, infra-red spectroscopy and X-ray diffraction to be of two types: depolymerization degradation of carbohydrates, and polymerization of extractives and lignin components. Differences in thermal behaviour of softwoods and hardwoods are noted. The experiments also included materials of two other conifers and two other hardwoods, but results are given in detail only for P. menziesii and A. rubra." (FA)

103. Clark, Donald H.  
1955. Alder comes of age. Pac. Coast Hardwoods (Fall):6-7. Northwest Hardwood Assoc., Seattle, Wash.

Discussion of properties, uses, and future of red alder as a commercial species. (CFH)

104. Clark, Donald H.  
1955. Forest industry survey of Lewis County, Washington. New Wood-Use Ser., Inst. For. Prod. Circ. 29, 33 p. Univ. Wash., Seattle.

In 1955, there was 98 million board feet of red alder in Lewis County, Washington. This was 58 percent of all hardwoods. (CFH)

105. Clark, Donald H.  
1956. Alder forsakes Cinderella role. West. Conserv. J. 13(1):30-31, 51-52.

106. Clark, Donald H.  
1956. Hardwood timber inventory of Snohomish County, Washington. Inst. For. Prod. Circ. 31, 13 p. Univ. Wash., Seattle.

Statistical data resulting from a field survey of various hardwood types in Snohomish County, Washington, USA, taken in the summer of 1955. Contains tables and charts of volumes of various species, mainly red alder. Makes recommendations for management, harvest, and marketing. (CFH)

107. Clark, Donald H.  
1956. Hardwoods offer pulping resources. West. Conserv. J. 13(6):20-22.

Considers hardwoods and especially red alder as pulpwood. Discusses production methods, pulpwood specifications, measurement, and availability. (CFH)

108. Clark, Donald H.  
1957. Developments in the use of red alder. For. Prod. J. 7(11):17A-20A.

"Pacific Coast red alder, a fast-growing, aggressive tree, is emerging from commercial obscurity into a position of distinct value in the forest products field. It has been added to softwoods as a desirable material for several types of paper. Increased utilization forecasts a future demand that may equal the available supply in Oregon, Washington, and British Columbia." (A)

109. Clark, J. B., and G. R. Lister.  
1973. A comparative study of the photosynthetic action spectra for a deciduous and four coniferous trees. (Abstr.) Plant Physiol. 51(Suppl.):20.

110. Clark, John B., and Geoffrey R. Lister.  
1975. Photosynthetic action spectra of trees. I. Comparative photosynthetic action spectra of one deciduous and four coniferous tree species as related to the photorespiration and pigment complements. *Plant Physiol.* 55(2):401-406.

"Describes laboratory studies in which measurements were made of the relative spectral photosynthetic activities of 2-to 3-year-old field-grown seedlings of *Alnus rubra* (a) *Pseudotsuga menziesii* (b), *Picea sitchensis* (c), *P. pungens* (d) and *P. pungens* var. *hoopsii* (e). Compared with the red peak of photosynthetic activity, the relative rates of net photosynthesis in blue light were highest for the dark-green broad leaf of (a), intermediate for the green needles of (b) and (c), and lowest for the blue-green and blue-white needles of (d) and (e) respectively. Leaf form per se was not responsible for these results. The differences were more subtle, resulting from the differential operation of various photosynthesis-screening mechanisms. It is concluded that the relatively high carotenoid/chlorophyll ratio of the 'green' conifers, as compared with (a), is responsible for their relatively lower photosynthetic activity in blue light as a result of absorption screening of the chlorophyll by the extra carotenoids. For the 'blue' conifers, the additional factor of leaf colour is also involved, which differentiates them from the 'green' conifers." (FA)

111. Clark, John B., and Geoffrey R. Lister.  
1975. Photosynthetic action spectra of trees. II. The relationship of cuticle structure to the visible and ultraviolet spectral properties of needles from four coniferous species. *Plant Physiol.* 55(2):407-413.

"The relative reflectance spectra of needles of (d) and (e) that had been wiped to remove the bluish coloration from the needle surfaces, were very similar to those for the normal 'green' foliage of (b) and (c). Scanning electron microscopy of surfaces of unwiped needles of (d) and (e) revealed a system of wax filaments whose complexity was correlated with the degree of ultraviolet and blue reflectance. It is concluded that both the bluish appearance (glaucous bloom) and the low relative efficiencies of blue light in photosynthesis of (d) and (e) result from the selectively enhanced reflection of blue light caused by the presence of wax deposits on the cuticle." (FA)

112. Clark, Robert H., and Harold R. Offord.  
1926. The tannin content of British Columbian *Alnus rubra*. *Trans. Roy. Soc. Can.* 20(Sect. III):149-152.

"Alder being immune to the attacks of the teredo this wood is extensively used for piling. The authors investigated the commercial possibility of extracting tannin from the remaining portions of the tree. Analyses showed a rise in the tannin content up to late fall when a sudden drop occurred after the sap ceased to flow. This variation is similar to that of the western hemlock. The minimum tannin content of 2.79 percent occurred in

January and the maximum of 6.60 percent in March. This does not warrant a commercial extraction at the present time." (CA)

113. Cole, Dale W., S. P. Gessel, and John Turner.

1978. Comparative mineral cycling in red alder and Douglas-fir. In Utilization and management of alder, p. 327-336. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"A comparative study of mineral cycling between second-growth forests of red alder (Alnus rubra) and Douglas-fir (Pseudotsuga menziesii) was made at the Thompson research site within the Cedar River watershed, western Washington. Both sites have similar histories and are adjoining on glacial drift material. The rate of elemental cycling is far faster in alder than in Douglas-fir. The red alder ecosystem is accumulating 85 kg ha<sup>-1</sup> yr<sup>-1</sup> more nitrogen than the Douglas-fir, apparently through biological fixation. Greater percentages of the nutrients are stored within the trees and understory vegetation in the alder ecosystem, but these nutrients remain within the foliage and forest floor two to five times longer in Douglas-fir than in alder. Nutrient leaching losses are slightly higher within the alder ecosystem. This study helps clarify the role of red alder in second-growth forests and provides insight into the management of this type of ecosystem. (A)

114. Cole, Dale W., and Stanley P. Gessel.

1968. Cedar River research. A program for studying the pathways, rates, and processes of elemental cycling in a forest ecosystem. Contrib. Inst. For. Prod. 4, 54 p. Seattle, Wash.

"Describes the experimental area and its vegetation (which includes three principal types of forest cover: a 35-year-old Douglas Fir plantation and natural stands of ca. 35-year-old Douglas Fir and of 21-to 28-year-old Alnus rubra), the field instrumentation, and the methods used for recording and analysing the data, and summarizes the results of studies undertaken so far on (1) mineral and water transfer under natural-ecosystem conditions and (2) the influence of altering the ecosystem on the rates of transfer." (FA)

115. Collingwood, G. H.

1945. Red alder (Alnus rubra Bong.). Am. For. 51(3):126-127.

General silvical characteristics of red alder. (CFH)

116. Collingwood, G. H. and Warren D. Brush.

1955. Red alder Alnus rubra Bong. In Knowing your trees. p. 174-175. Am. For. Assoc., Washington, D.C.

The red alder section is a reprint of an article appearing in Collingwood (115). Similar articles appear in the 1964 and 1974 editions of "Knowing your trees." (CFH)

117. Commonwealth Bureau of Soils. 1971. Bibliography on soil relationships, nutrition and fertilizer of alder (Alnus spp.). Ser. 1455, 13 p. Harpenden, England.

A collection of 49 literature citations with abstracts pertaining to the relationship between alder and soil fertility. Red alder is one of the species discussed. (CFH)

118. Cooke, William Bridge. 1956. The genus Phlebia. *Mycologia* 48(3):386-405.

"A revision of the genus Phlebia based on 1560 collections in 25 herbaria is presented. The commonest spp., as indicated by synonymy and number of collections, are P. radiata and P. albida. Novelties based on morphological variation include Phlebia atkinsoniana from New York, P. argentinensis from Argentina, P. celtidis on Celtis from Idaho, P. cystidiata Jackson on Alnus rubra from California, P. subabida in Abies magnifica from California, P. canadensis on Acer, etc. from Ontario, and P. murrillii on Pinus from Florida. Five spp. were not available for study and 9 sp. previously assigned to Phlebia were excluded. The genus PHAEOPHLEBIA is proposed for P. strigoso-zonata (-Merulins strigoso-zonatus Schn.) which has 28 synonyms. Tendencies of development within the genus are noted, but it is suggested that when 78% of the spp. treated are represented by less than 5% of the specimens studied, conclusions are difficult to make." (BA)

119. Corliss, J. F., and C. T. Dyrness. 1965. A detailed soil-vegetation survey of the Alsea area in the Oregon Coast Range. In Forest-soil relationships in North America, p. 457-483. Chester T. Youngberg, ed. Oreg. State Univ. Press., Corvallis.

120. Cowan, I. M. 1945. The ecological relationships of the food of the Columbian black-tailed deer, Odocoileus hemionus columbianus (Richardson), in the coast forest region of southern Vancouver Island, British Columbia. *Ecol. Monogr.* 15:109-139.

"The coast deer of British Columbia is primarily an inhabitant of pioneer forest communities. Logging may be directly responsible for producing improved conditions for this ungulate. Optimum conditions for coast deer occur where a rolling or broken terrain supports a diversified cover in which young second-growth forests predominate but where blocks of older timber are interspersed. Current reforestation practice with Douglas Fir (Pseudotsuga taxifolia) planted at approximately 1,200 per acre provides conditions under which maximum damage by deer can be expected. Where natural or artificial seeding gives rise to seedlings in excess of 12,000 per acre, deer damage is found to be unimportant.

"Examination of food plants in the field and in deer stomachs revealed that 67 per cent of the annual diet consisted of twigs and leaves of trees and shrubs (24 per cent conifer browse and 43 per cent deciduous browse). The most important woody species browsed in the Goldstream area were Douglas Fir (Pseudotsuga taxifolia), Alder (Alnus rubra), Willow (Salix sp.) and Cedar (Thuja plicata).

Browsing upon seedling and second-growth Douglas Fir was particularly severe on inferior forest sites. Two types of Douglas Fir (normal trees and yellow trees) were noted among the natural regeneration on southern Vancouver Island. The latter had a significantly lower palatability than the former. Since Western Hemlock (Tsuga heterophylla) is not browsed by deer, it is suggested that this species might be used for artificial reforestation in areas where deer are abundant.

"Tables are given showing the relative palatability to deer of plants found in southern Vancouver Island, and the extent to which species in the various communities are utilized--their abundance, period of availability, period of utilization, and importance as deer food. Douglas Fir (as represented by young trees) is the most important single food item in the diet of the Columbian black-tailed deer." (FA)

121. Cowlin, Robert W., and Robert M. Forster.  
1965. The timber situation and outlook for northwest Oregon.  
USDA For. Ser. Resour. Bull.  
PNW-12, 56 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Contains volume and acreages for red alder in northwest Oregon. (CFH)

122. Crouch, Glenn L.  
1966. Preferences of black-tailed deer for native forage and Douglas-fir seedlings. J. Wildl. Manage.  
30(3):471-475.

"Choice of browse by Odocoileus hemionus columbianus in an enclosure carrying native vegetation and some planted Douglas Fir was closely related to the weather.

Blackberry leaves were most highly preferred so long as they were available. Douglas Fir ranked higher in preference than most common woody plants, which included Alnus rubra, Corylus californica, and Acer circinatum." (FA)

123. Crouch, Glenn L.  
1968. Clipping of woody plants by mountain beaver. J. Mammal.  
49(1):151-152.

"Shrubs and small trees in areas occupied by Aplodontia rufa often have bushy, open, uneven crowns or atypical forms as a result of clipping of stems and branches. Acer circinatum was the most frequently clipped plant in 1963 on 110 plots; other species damaged included Alnus rubra, Acer macrophyllum, Corylus cornuta and Salix sp." (FA)

124. Curtis, Robert O., David Bruce, and Caryanne VanCoevering.  
1968. Volume and taper tables for red alder. USDA For. Serv. Res. Pap. PNW-56, 35 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Basic data used consisted of tree measurement data of Alnus rubra from Oregon, Washington and British Columbia, additional data from Washington and Oregon, and data for tables originally published in 1926; a total of 473 trees was available for analysis." (FA)

125. Curtis, Robert O., Donald J. DeMars, and Francis R. Herman. 1974. Which dependent variable in site index-height-age regressions? *For. Sci.* 20(1):74-87.

"Two regressions relating height and site index can be calculated from stem analysis data. Site index estimation curves obtained by regressing site index on height and age differ from height growth curves obtained by regressing height on site index and age. The first provide estimates of site index for stands of known present age and height, while the second provide estimates of expected height at different ages for stands of specified site index. The traditional type of height over age 'site index curve' does not provide optimum estimates of site index. Magnitude and practical importance of differences depend on the amount of unexplained variation present. Appropriate uses of the two systems of curves and some sources of bias are discussed." (A)

126. Dahms, W. G. 1958. Chemical control of brush and undesirable hardwoods on forest land of the Pacific Northwest. (Abstr.) *Weed Soc. Am.* 1958:29.

"An aerial foliage spray of 2,4-D or 2,4,5-T controlled Alnus rubra; some species of Arctostaphylos and Ceanothus were killed, others resprouted; Castanopsis chrysophylla, Quercus chrysolepis and Lithocarpus densiflorus were lightly damaged. A basal spray was most promising for Rubus spectabilis, and a dormant-season aerial spray for Acer circinatum; both species resprouted after foliage spraying." (FA)

127. Darlington, C. D., and A. P. Wylie. 1956. Chromosome atlas of flowering plants. 2d ed. p. 179-180. MacMillan Co., New York.

Red alder has 28 chromosomes (n=14). (CFH)

128. Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetational classification. *Ecol. Monogr.* 22:301-330.

129. Daubenmire, R. 1969. Ecologic plant geography of the Pacific Northwest. *Madrono* 20(3):111-128.

"The purpose of this phytogeographic sketch is to provide an introduction to the natural vegetation of the Pacific Northwest for the use of botanists from other areas who will be attending the XI International Botanical Congress in Seattle in 1969. Attention will be centered on the State of Washington, with secondary emphasis on the adjoining areas. If my friends in British Columbia feel that I have slighted their Province, this is more a consequence of maps terminating at the international border than of any intent of mine to confine attention to the 'Pacific Northwest'--a nationalistic and ambiguous though useful term, which I shall not try to define!"

"The visitor, like some of us who reside here, may be appalled by the scarcity of natural vegetation in a region which was opened up by white explorers as late as 1805 (the Lewis and Clark expedition). Nevertheless the account is centered on remnants of natural vegetation with the intent of helping the visitor recognize some of the common types and see how they fit into a regional pattern." (A)

130. Davis, E. M.  
1960. Machining properties of red alder and bigleaf maple. *Wood-Worker*, Indianapolis 78(11):10-25.

"Gives brief results of recent U.S. planning, shaping, turning, boring, and mortising tests with Alnus rubra and Acer macrophyllum." (FA)

131. Davis, E. M.  
1962. Machining and related characteristics of United States hardwoods. *U.S. Dep. Agric. Tech. Bull.* 1267, 68 p. Washington, D.C.

Discusses and presents tables of response of various woods to planing, shaping, turning, boring, mortising, sanding, steam binding, nail and screw splitting, specific gravity, annual rings per inch, cross grain, shrinkage, warp, and changes of color. (CFH)

132. Davis, Margaret Bryan.  
1973. Pollen evidence of changing land use around the shores of Lake Washington. *Northwest Sci.* 47(3):133-148.

"Pollen diagrams from near-surface sediments in Lake Washington record changes in the vegetation around the lake since the mid-19th century. The primeval conifer forests produced a pollen assemblage dominated by pollen from Douglas-fir, cedar, and hemlock, with minor amounts of pollen from pine, fir and spruce. Sediments 30-45 cm beneath the surface were deposited during the early years of settlement around Lake Washington between 1860 and 1890. They record minor changes in the vegetation as limited areas were logged. Douglas-fir was the major species cut at the time. Alder pollen reflects the first sharp increase in alder

trees as succession took place on disturbed sites. A much greater increase of alder followed the intensive logging operations of the 1880's. The growth of Seattle and the cutting of second-growth forests in recent years have reduced the amount of locally produced alder pollen. The changes that served as culture indicators in the pollen diagram from Lake Washington are interesting from the theoretical point of view. In Washington, the logging horizon is conspicuous because the conifers, which in this case are poor pollen producers, are temporarily replaced by a successional species (red alder) that is a heavy pollen producer." (BA)

133. Dayton, William A.  
1931. Important western browse plants. *U.S. Dep. Agric. Misc. Publ.* 101, 214 p. Washington, D.C.

134. DeBell, D. S.  
1971. Progress report on red alder study. 6 p. *Cent. Res., Crown Zellerbach Corp., Camas, Wash.*

135. DeBell, Dean S.  
1972. Potential productivity of dense, young thickets of red alder. *For. Res. Note 2*, 7 p. *Crown Zellerbach Corp., Camas, Wash.*

"Total above-ground production was evaluated in 28 natural alder thickets, aged 1 to 14 years. On a per acre basis, mean annual production varied from 3 to more than 20 tons of green wood per acre. Such yields warrant preliminary trials of short-rotation cultural systems with red alder." (A)

136. DeBell, Dean S.  
1975. Short-rotation culture of hardwoods in the Pacific Northwest. Iowa State J. Res. 49(3):345-352.

"In the late 1960's, innovative ideas on silage wood were published. Since then, interest has been generated in short-rotation culture of hardwoods in the Pacific Northwest, and has been accompanied by experimentation attempting to increase yields from this type of culture. Major factors included in programming the experiments were suitable sites; relative productivity of black cottonwood and alder; cultural practices including weed control, fertilization, and organic amendments and irrigation; and kraft pulping of juvenile hardwoods." (A)

137. DeBell, Dean S., Robert F. Strand, and Donald L. Reukema.  
1978. Short-rotation production of red alder: Some options for future forest management. In Utilization and management of alder, p. 231-244. David. G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Many options are available to foresters who may want to consider management of red alder (Alnus rubra Bong.). Four options are discussed in this paper--a coppice system and three high forest systems: pulpwood log, saw-log and peeler, and pulpwood log and saw-log production. Coppice can be grown on 4-to 6-year rotations and pulpwood logs can be produced in 10 to 15 years on most sites. Estimated yields (per acre per year) of these options are about double those obtained in natural stands. Saw logs and peelers can probably be grown in 28 to 37 years, and yields are

estimated to be about 40 percent higher than those listed in normal yield tables for well-stocked stands." (A)

138. DeBell, Dean S., and Boyd C. Wilson.  
1978. Natural variation in red alder. In Utilization and management of alder, p. 193-208. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"An 8-year-old provenance trial examined racial variation among 10 sources of red alder from Alaska, British Columbia, Washington, Oregon and Idaho. The fastest growing sources are from northwestern Washington, and Oregon also grew well. The slowest growers were from Juneau, Alaska, and Sandpoint, Idaho--they also have the greatest frost resistance.

"A study of phenotypic variation between and within eight stands was conducted in a small area west of Olympia, Washington. Although the stands were selected to cover the range in site conditions occurring in the area, only crown width index, branching characteristics, and bark thickness showed significant variation between stands. Variation from tree to tree within stands, however, was substantial for all traits.

"The results of these studies suggest that individual tree selection will be a useful approach in alder improvement programs and that such programs can encompass rather large areas (or breeding zones.") (A)

139. DeFreitas, Amantino R., and Harvey D. Erickson.

1969. Propagation of molds on red alder roundwood--their effect on oil soak treatments. For. Prod. J. 19(10):45-52.

"Growth of four fungi including Trichoderma sp., Fusarium sp., Gliocladium roseum, and Chaetomeum cochlioides was satisfactory on the wood only when a fluoride salt was present. Concentrations of 1.5 to 3.0 percent were near optimum. Other additives tried were not helpful. Trichoderma sp. was the dominant fungus from a mixture inoculation. Light steaming caused only a short-term growth advantage. Good fungal growth produced twice the oil absorption of non-infected wood. Trichoderma was usually the best. Leaving inner bark on before inoculation caused no real decrease in oil absorption after 4 weeks of fungal growth. It seems unnecessary to remove the inner bark before inoculation. Exploratory tests indicated vacuum impregnation was much more effective than cold soak. The hyphae traveled through all types of cells in the wood and even pierced fiber walls." (A)

140. DeFreitas, Amantino Ramos.

1966. Stimulation of several mold growths on red alder and their effects on cold-soak treatment. M.F. thesis. Coll. For. Resour., Univ. Wash., Seattle. 91 p.

141. DeMoisy, Ralph G.

1952. Progress report on chemical debarking. Inst. For. Prod. Circ. 19, 4 p. Univ. Wash., Seattle.

"Several methods of girdling the trees and applying  $\text{Na}_2\text{HAsO}_3$  solution for barking pulpwood species have been

tested. Western Hemlock, Firs, Black Cottonwood and Western Red Cedar have been successfully treated. Results for Douglas Fir are disappointing. Bark separation tests with Red Alder are incomplete, but no separation had occurred after 160 days. Future plans are discussed, and additional information is given on crew organization and treating techniques, safety precautions and patent rights." (FA)

142. Detling, LeRoy E.

1968. Historical background of the flora of the Pacific Northwest. Univ. Oreg. Mus. Nat. Hist. Bull. 13, 57 p. Eugene, Oreg.

"The modern flora of the Pacific Northwest is characterized by associations which show affinities to floras now occupying widely separated areas (Eurasia, South and Central America) and to floras shown by paleo-botanical evidence to have occupied all these areas, but particularly the American West. Distinct distribution patterns, both in time and space, manifest themselves. These patterns are and have been influenced by topographic and climatic changes from the Cretaceous to the present. Three principal sources of associations are evident: evolution in situ; northern regions as shown in the Arcto-Tertiary Geoflora; western Mexico and the southwestern United States as shown in the Madro-Tertiary Geoflora." (A)

143. Diehl, William W.

1955. Valsaria megalospora on red alder. Plant Dis. Rep. 39(4):334.

144. Dimock, Edward J., II, Enoch Bell, and Robert M. Randall.  
1976. Converting brush and hardwood to conifers on high sites in western Washington and Oregon--progress, policy, success and costs. USDA For. Ser. Res. Pap. PNW-213, 16 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Evaluates opportunities, techniques, success and cost of brushland reclamation efforts for almost a 20-year period. Among newer techniques, slash-and-burn and spray-and-burn are consistently more successful--and more economical per established conifer--than multiple-spray conversions." (A)

145. Dixon, D.  
1961. These are the champs. Am. For. 67(1):40-46, 48-50.

146. Dobie, J.  
1966. Product yield and value, financial rotations and biological relationships of good site Douglas fir. M.F. thesis. Univ. B. C., Vancouver. 141 p.

"Quantity and value of the assortment yield of four natural stands (age 63-145) of Douglas Fir in British Columbis were analysed, using linear programme techniques to determine the optimum assortment yields from each stand. Financial rotations at two levels of established costs and three interest rates were examined, and mathematical models of the relationship between tree value, tree volume, and biological variables are presented. It was found that the new value per cu. ft. of tree increased with tree size and that, at the level of costs and values used, it is more profitable to produce

piling from small logs and plywood from large trees rather than lumber. Optimum conversion returned for all stands was 5 cents/cu. ft. greater than the lumber conversion return. Financial rotations at 3% compound interest on establishment costs and on the value of growing stock are 60-70 years for these sites. Many biological variables were found to be correlated with tree value and volume. Combinations of d.b.h., butt-log grade, and crown class were the best 2- or 3-variable models for value prediction; tree d.b.h. and  $D^2H$  gave similar estimates of bd. ft. and cu. ft. volumes." (FA)

147. Doran, Samuel M., Joseph Buhaly, and Loren Curry.  
1971. Red alder costs and returns for western Washington. Coop. Ext. Serv., Coll. Agric., Wash. State Univ. Study EM 3461, 33 p. Pullman, Wash.

"Describes a study to determine the income and costs normally associated with the production of Alnus rubra timber in western Washington, and to determine the age (for most sites, ca. 50 years) at which it should be harvested for maximum profit." (FA)

148. Douglas, David.  
1959. Journal kept by David Douglas during his travels in North America 1823-1827. 364 p. Antiquarian Press Ltd., New York.

Douglas first collected red alder (plant collection #11) on April 8, 1825, on the north shore of the Columbia River at Cape Disappointment. His journal reveals: "(11) Alnus sp.: a tree 50 to 70 feet high; may prove A. glutinosa; its size occasioned by the richness of the soil and finer climate; most places on the Columbia; April." (CFH)

149. Douglas-fir Second-Growth Management Committee.  
1947. Management of second-growth forests in the Douglas-fir region. 151 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Report deals with regeneration and management of Douglas-fir in the Pacific Northwest, with red alder considered mainly as a competing species; however, there is a short discussion of red alder management. (CFH)

150. Dreyer, H. V.  
1928. Skyldes rodellens sygelighed froets proveniens? [Is the sickliness of red alder due to the source of the seed?] Dan. Skovforen. Tidsskr. 13:229-376.

"Investigations confirm the belief that the sickliness of alder in Denmark is due to the kind of seed and its origin. Native seed produced healthy individuals, but imported seed produced sickly trees. Alder is very valuable as an advance crop in improving the condition of the soil because of its nitrogen-fixing capacity. It should be planted especially on lands which are not suitable for ash." (BA)

151. Driver, Charles H.  
1978. Red alder management and diseases. In Utilization and management of alder, p. 271-272. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Ser. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Relatively little is specifically known about diseases of red alder with respect to management. The status of reports in the literature concerning the subject is

outlined. Research remains to be conducted on the part played by diseases of this species in respect to management." (A)

152. Duffield, John W.  
1956. Damage to western Washington forests from November 1955 cold wave. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 129, 8 p. Portland, Oreg.

A survey of the damage, with maps showing location and relative severity of damage. (CFH)

153. Eklundh, C.  
1944. Report on alder, ash and elm. In Arsberättelse over Foreningens för vaxtförädling av skogsträd verksamhet under år 1943. [Annual report on the work of the Association for Forest Tree Breeding during the year 1943.] Sven. Papp Tidn. 47, 38 p. [Suppl.] [In Swedish.]

"In spring 1943, bottle grafting of Alder species was carried out for the first time, and gave 25 per cent success. Alnus glutinosa was used as stock for scions of A. glutinosa, A. incana, A. cordata, A. subcordata, A. rubra, A. hirsuta, and some Danish material. The method used with promising results in Denmark for maintaining a 'live seed store' for valuable hybrid seed was tried, grafting A. cordata scions 10-15 cm. long in older stands of A. glutinosa in which trees about 15 cm. in diameter had been cut to breast height for use as stocks.

"Crosses were made with the bottle grafts, grown in the illuminated greenhouse, of A. glutinosa with A. cordata,

A. incana or A. rubra and of A. subcordata with A. glutinosa or A. cordata. Some fruits were obtained and the seed will be sown in spring 1944.

"In the vegetative propagation experiments about 10 plus-variants selected from two-year-old plants with the greatest average increment were planted and layered, the branches undergoing treatment with hormone paste or strangulation to induce the formation of adventitious roots. Good results were obtained.

"One- and two-year-old colchicine-treated Alders were grown on in pots to obtain early flowering, or raised in the arboretum, where some of the plants were strangulated. Investigation of the stomata and chromosome number in these supposedly mixoploid plants showed that the root-tip cells were predominantly diploid, whereas the variation in the size of stomata suggested that the shoot system had retained its mixoploid character to a greater extent. It is hoped, by vegetative propagation, to obtain pure tetraploids from some buds of these plants." (FA)

154. Erickson, Harvey D.  
1957. Wood supply and production of the pulp industry in the State of Washington. New Wood-Use Ser., Inst. For. Prod. Circ. 32, 38 p.  
Univ. Wash., Seattle.

Red alder is growing in importance as a pulp species. It presently ranks number four in pulp volume, comprising 31 percent of total. (CFH)

155. Erickson, Harvey D., and Amantino R. DeFreitas.  
1971. Influence of various molds and seasoning on vacuum light-oil treatment of round red alder (Alnus rubra Bong.). For Prod. J. 21(4):53-58.

"Vacuum treatment for 45 or 75 min. of specimens incubated for 4-6 weeks after inoculation with one of four fungi (Trichoderma harzianum, Gliocladium roseum, Chaetomium cochlioides or Fusarium sp.) gave greater retentions and penetrations of PCP in light oil than did similar treatment of uninoculated controls that had been barked and stored green for 4 or 6 weeks. There was little difference in the effect of the different fungi. Absorptions about equal to those for vacuum treatment after incubation with the fungi were obtained in wood barked immediately after cutting and then dried. A modified hot-and-cold treatment of wood after incubation with Trichoderma was less effective than vacuum treatment. Vacuum treatment of wood after 18 days' laboratory storage before barking and drying gave retentions little better than a cold-soak treatment of wood incubated with Fusarium, which was the poorest of all treatments." (FA)

156. Esau, Katherine, and Vernon I. Cheadle.  
1955. Significance of cell divisions in differentiating secondary phloem. Acta Bot. Neerl. 4(3):348-357.

"With regard to the frequency of anticlinal divisions in the phloem initials the 77 general investigated by the authors fall into 3 groups: (1) anticlinal divisions none or infrequent

(Acer, Rhus, Berberis, Celastrus, Alnus, Quercus, Aesculus, Juglans, Lardizabalae, Gymnocladus, Fraxinus, Pyrus, Prunus, Populus, Tilia); (2a) anticinal divisions common and mainly transverse or slightly oblique (Buxus, Viburnum, Weigelia, Cercidiphyllum, Clethra, Cornus, Rhododendron, Azara, Hypericum, Paulownia, Ailanthus): and (2b) anticinal divisions common and mainly vertical or strongly oblique (Annona, Asimina, Michelia, Paeonia, and all 9 genera of Lauraceae used in this study). The derivatives of these divisions consist either of sieve elements with their companion cells and parenchyma cells. Frequently the divisions result in sieve elements shorter than their mother cells." (BA)

157. Eslyn, W. E., T. K. Kirk, and M. J. Effland.  
1975. Changes in the chemical composition of wood caused by six soft-rot fungi. *Phytopathology* 65(4):473-476.

"Outer-xylem blocks of Alnus rubra, Populus balsamifera and Pinus monticola were exposed to six soft-rot fungi isolated from pulp-chip storage piles, viz. Graphium sp., Monodictys sp., Papulospora sp., Paecilomyces sp., Thielavia terrestris and Allescheria sp. Samples of wood at different weight losses were analysed for lignin and polysaccharides (flucan, xylan and mannan). Polysaccharides were depleted faster than lignin in Alder and Poplar. Lignin was depleted by all the fungi. Graphium sp. appeared to increase the mannan content of Alder. Pine was not decayed significantly by Graphium sp., Monodictys sp. and Allescheria sp.; the other fungi caused small weight losses. In Pine, lignin was depleted faster than polysaccharides by Paecilomyces and T. terrestris." (FA)

158. Espenas, Leif D.  
1951. The seasoning of Oregon hardwoods. Oreg. For. Prod. Lab. Inf. Circ. 6, 35 p. Corvallis, Oreg.

"Kiln schedules for green stock are given for: Red Alder, Cottonwood, Oregon Ash, Oregon Maple, Myrtle (California Laurel), and Madrone. Kiln schedules for air-dried stock are given or suggested for Tan Oak, Chinquapin, California Black Oak, and Oregon White Oak." (FA)

159. Espenas, Leif D.  
1971. Shrinkage of Douglas-fir, western hemlock and red alder as affected by drying conditions. *For. Prod. J.* 21(6):44-46.

"When specimens were dried at temperatures from 90 to 230°F to give equilibrium moisture contents (EMC) of 6, 9 or 12% (6% only at 230°C), moisture content after equilibrating at room temperature decreased with increasing drying temperature. Shrinkage increased with increasing drying temperature and was greatest for the highest EMC. Compared with shrinkage at 90°C, shrinkage at 215° was greater by 33% tangentially and 51% radially for Douglas Fir, 65 and 82% respectively for Hemlock, and over 100% for Alder when EMC was 12% throughout; at 6% EMC, the corresponding figures were 30 and 33%, 17 and 18%, and 41 and 49%. Increase in shrinkage could not be accounted for by differences in EMC. Temperature effects were greater above than below 150°C." (FA)

160. Evans, Harold J., and Mark Kliewer. 1964. Vitamin B<sub>12</sub> compounds in relation to the requirements of cobalt for higher plants and nitrogen-fixing organisms. Ann. N.Y. Acad. Sci. 112:735-755.

Red alder root nodules show nine cobamide coenzyme content of 24-62 micromoles per gram of fresh tissue. That is among the highest of 15 species reported. The role of cobamide coenzymes in nitrogen-fixing organisms is discussed. There is insufficient evidence to determine whether the function of B<sub>12</sub>-coenzymes in N-fixing organisms is different from that in those that do not fix nitrogen. (CFH)

161. Evans, R. S.

1974. Energy plantations--should we grow trees for power-plant fuel? West. For. Prod. Lab. Inf. Rep. VP-X-129, 15 p. Vancouver, B.C.

"Examines the prospects of operating a power station using as fuel tree crops grown on a sustained-yield basis in North America. It is calculated that for most regions of North America the outlook is not promising, the land area required to sustain a 150 Mw power unit being from 240 to more than 100 sq. miles, depending on the species. Conditions in the Pacific north-west are more favourable, especially for Red Alder (Alnus rubra), the growth rate of which is such that a power plant of this size might be sustained by a plantation of 65 sq. miles. Economic considerations and the use of fertilizers are not taken into account." (FA)

162. Faegri, Knut.

1968. A note on the maritime forest limit in south-east Alaska. Arbok Univ. Bergen (Mat.-Naturvitensk. Ser.) 1968(5), 20 p.

"On the Alaskan coast near Juneau, in a region of virgin (Picea sitchensis)/Psuga heterophylla climax forest, a narrow belt of Alder fringes the conifer forest towards the beaches, but is absent from the most exposed situations, presumably because of wind; on part of this Alder-free stretch conifers form the extreme limit of the vegetation, but on the headlands small meadows lie between the bare rocks and the forest edge, carrying a few very unstunted Sitka Spruce. Pollen analysis and radio carbon dating suggest that these meadows are of comparatively recent origin (formed perhaps ca. 2500 years ago) and that there have also been fairly recent changes in forest composition from Alnus/Pinus to spruce, possibly owing to increased winds. The findings suggest that, under purely natural conditions, there might also be a very narrow un-forested belt on very exposed sites in Western Norway." (CA)

163. Faurot, James L.

1957. An economic analysis of red alder pulpwood logging methods in western Washington. M.F. thesis. Coll. For. Resour., Univ. Wash., Seattle. 56 p.

Small scale logging costs of red alder pulpwood are analyzed. Bucking, yarding, loading, and hauling factors are considered. The most economical operations are with a three-person crew cutting 16-foot logs and hauling them less than 50 miles. Alder pulpwood production is concluded to be economically marginal. (CFH)

164. Fay, Ginny, Polly Hessing, Karen Jacobsen, and Karen Oakley.  
1975. Alder-cedar forest. Am. Birds 29(3):764.

Results of 24th winter bird population census. Done in an alder-cedar forest in Thurston County, Washington, U.S.A. Relative tree frequency was 57 percent red alder. Twenty species of birds were observed at rate of 857 birds per square kilometer. (CFH)

165. Fay, Ginny, Polly Hessing, Karen Jacobsen, and Karen Oakley.  
1975. Douglas-fir forest. Am. Birds 29(3):764-765.

Results of the 24th winter bird population census. Done in a Douglas-fir forest in Thurston County, Washington, U.S.A. Red alder comprised 12.8 percent of tree species. Seventeen species of birds observed at rate of 888 birds per square kilometer. (CFH)

166. Feddern, Edward T.  
1978. Harvesting of red alder.  
In Utilization and management of alder, p. 61-69. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The harvesting and marketing of red alder from the Oregon Coastal Counties requires a company to address itself to several major concerns before entering a major program.

"A few of these would be the availability of an efficient contracting force, manpower, harvesting equipment, labor and overhead costs, and the availability of a continuing market. Also, operating seasons in relationship with

inventory control, lack of demand for all log grades, sizes and species, capabilities of sawmills to market residuals and adequate log storage facilities." (A)

167. Field, Nancy, and David A. Manuwal.  
1973. Clearcut in Douglas-fir forest. Am. Birds 27(6):1003-1004.

Results of a bird census on a clearcut in a Douglas-fir forest in the Cedar River watershed, King County, Washington. Regeneration was occurring with red alder equaling 11.6 percent of the stand. Ten species were observed at a density of 561 birds per square kilometer. (CFH)

168. Finnis, J. M.  
1964. Chemical frill treatment of alder. West. Weed Control Conf. Res. Progr. Rep. 1964:47.

"Alnus rubra, treated in late Aug. with dicamba at 4 lb./gal. undiluted with an aqueous solution of NH<sub>4</sub> sulphamate at 1 lb. in 1 pint water applied to axe cuts spaced 4 in. apart around the stems, died by late Oct." (FA)

169. Finnis, J. M.  
1970. "Brown and burn" as a means of site preparation. West. Soc. Weed Sci. Proc. 23:47.

"The dense understorey remaining after logging Alder (Alnus rubra) stands (in coastal Washington) can be desiccated with dinoseb at 1 gal in 9 gal water/acre and ignited in one mass by 7 cans of jellied petrol/acre joined by primacord; the resulting series of flash fires gives a clean burn and facilitates planting." (FA)

170. Fonda, R. W.  
1974. Forest succession in relation to river terrace development in Olympic National Park, Washington. *Ecology* 55(5):927-942.

"The floodway zone of the Hoh River exhibits four terrace levels of different ages, formed by erosional activity of the river on valley fills. The vegetation in this valley is in a long-term seral sequence as shown by the zonal pattern in relation to aging and development of these land surfaces. Succession starts on gravel bars, which are dominated by Alnus rubra and Salix scouleriana. The following sequential forest communities, and associated ages of land surfaces, are found: Alnus rubra on alder flats (80-100 yr); Picea sitchensis-Acer macrophyllum-Populus trichocarpa on first terraces (400 yr); Picea sitchensis-Tsuga heterophylla on second terraces (750 yr); and Tsuga heterophylla on third terraces. The latter represents the climax community for the river terrace sere, and it occurs on surfaces exposed by retreating Pleistocene alpine glaciers. The first three terraces are derived from Neoglacial alluvial fills.

"There is strong correlation among zonation patterns, forest succession, age of terraces, soil moisture, and soil profile development. Available soil moisture is an important factor governing the zonal sequence. The younger land surfaces are significantly drier than the older terraces. Plants on alder flats and first terraces must withstand greater moisture stress than those of second and third terraces. As the land surface ages, the soil profile develops; deeper, more mature soils are found away from the river.

"The term 'Olympic rain forest' is inappropriately applied to this vegetation; 'temperature moist coniferous forest' is more appropriate not only for forests in the Hoh Valley, but also for

the rest of the Olympic Mountains and vegetation along the northern Pacific coast." (A)

171. Fontnoire, Jean.  
1974. Les aunes. [The alders.] La Forêt Privée Fr. 97:21-37. [In French.]

172. Forbes, Reginald D., Ed.  
1955. Forestry handbook. 1,174 p. Ronald Press Co., New York.

Contains a red alder volume table. (CFH)

173. Forest Club, University of British Columbia.  
1959. Forestry handbook for British Columbia. 2d ed. 800 p. Vancouver, B.C.

Compilation of useful forestry data tables and information, much of it pertaining to red alder. (CFH)

174. Forest Industries.  
1972. New drive behind red alder. For. Ind. 99(11):41.

"Red alder, for many years simply tolerated by land managers, had found increasing favor with furniture and novelty manufacturers. Production of red alder lumber in Washington and Oregon rose 50 million bd ft between 1960 and 1970, from 200 million to 250 million. Though utilized since the late 1800's, the species did not really get going until

after WW II. Four factors were the key to broader use: Technological advances in alder pulping, gradual decline in quality in other hardwoods on a national scale; expansion of nearby markets; and promotion efforts by an organization of Northwest hardwood producers and landowners.

"Red alder makes up about 70% of total volume of three principal hardwoods in coastal Oregon and Washington, followed by bigleaf maple and cottonwood. USFS data show that about 892,000 acres of commercial forest land in the two states are predominantly alder stands.

"Prior to WW II, much alder was sold on a rough, green, mill-run basis and a bad reputation resulted. Production since then has been more rigid, in mills equipped to accurately saw, kiln, dry, and surface the lumber to specification.

Seldom growing at elevations above 2,500 feet, alder often forms pure stands of up to several hundred acres. It does best along streams and bottom lands. In such stands, the timber may be clear-boled for 50-60% of its height. Heights of 65-100 feet are normal, though some reach 130 feet. Diameter ranges are from 18 to 24 in., with a maximum of about 34 in.

"About 18.6 billion bd ft of alder is available in commercially operable stands, nearly all west of the Cascades and about 65% on private land." (A)

175. Forest Record, Forestry Commission, London, United Kingdom. 1970. Trials of species on peats: Alder. For. Res. For. Comm., London Rep. 1969/70:51-52.

"Trees in a single plot of Oregon Alder (Alnus rubra) on a deep infertile peat in Sutherland have reached a height of ca. 2 m. in two seasons after planting

and fertilizing with P and K. A subsequent review of information on this and other Alnus spp. indicated, however, that although several species make rapid initial growth on acid peats, a characteristic deterioration takes place after 10-15 years, probably owing to lack of P and K. Further work on the nutrition of A. rubra has been planned." (FA)

176. Forristall, Floyd F., and S. P. Gessel. 1953. Soil properties related to forest cover type and productivity on the Lee Forest, Snohomish County, Washington. Soil Sci. Soc. Am. Proc. 19(3):384-389.

"Mechanical and chemical properties of the forest floor and soil, and soil moisture content were examined for 5 plots stocked respectively with Pseudotsuga taxifolia, Tsuga heterophylla, Thuja plicata and Alnus rubra, for each of which site class, number of trees, b.a., and volume and growth per acre were determined. Depth of hardpan layer was an important criterion for productivity rating. The dominating influence seemed to be soil drainage." (FA)

177. Fowells, H. A. 1965. Red alder (Alnus rubra Bong.). In Silvics of forest trees of the United States, p. 83-88. U.S. Dep. Agric. Agric. Handb. 271. Washington, D.C.

"A description of the silvical characteristics of red alder."

178. Franklin, Jerry F., and C. T. Dyrness.  
1969. Vegetation of Oregon and Washington. USDA For. Serv. Res. Pap. PNW-80, 216 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Describes and illustrates major vegetational types found in Oregon and Washington including forest types, steppe and shrub-steppe communities, and subalpine mosaics. Successional and environmental relationships of the communities are discussed. An extensive bibliography directs the reader to more detailed sources." (A)

179. Franklin, Jerry F., and C. T. Dyrness.  
1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Major vegetational units of Oregon and Washington and their environmental relationships are described and illustrated. After an initial consideration of the vegetation components in the two States, major geographic areas and vegetation zones are detailed. Descriptions of each vegetation zone include composition and succession, as well as discussion of variations associated with environmental gradients. Three chapters treat the forested zones found in the two States. Major emphasis is on the distinctive mesic temperate forest found in western Washington and northwestern Oregon. The interior valley forests, shrub lands, and prairies found between the Coast and Cascade Ranges in western Oregon are treated in a single chapter as are subalpine and alpine mosaics of tree-dominated and meadow communities.

Unusual habitats, such as areas of recent vulcanism, serpentines, and ocean strand, are individually described. Soils, geology, and climate are considered in broad outline in an early chapter and in greater detail within discussions of individual geographic areas and vegetation zones. Appendices are included for definition of the various soil types, scientific and common plant names, and a subject index. An extensive bibliography is included to direct the reader to other references." (A)

180. Franklin, Jerry F., C. T. Dyrness, Duane G. Moore, and Robert F. Tarrant.  
1968. Chemical soil properties under coastal Oregon stands of alder and conifers. In Biology of alder, p. 157-172. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Chemical soil properties were compared under (1) adjacent 40-year-old red alder (Alnus rubra), conifer (mainly Douglas-fir (Pseudotsuga menziesii)), and mixed stands and (2) adjacent 30-year-old alder and conifer stands growing on the Oregon coast. Soils on all sites were Astoria-like Sols Bruns Acides developed primarily from Eocene siltstone. Organic matter, total nitrogen, and acidity were significantly greater in A horizons under alder and mixed stands. In All horizons of the older stands, organic content under alder average one-third greater than conifer (39 vs. 29 percent), nitrogen one-third greater (0.8 vs. 0.6 percent), and pH one unit lower (4.3 vs. 5.3). A horizons under conifer stands average three times richer in bases than those under alder stands. Similar differences, but of a much smaller magnitude, were observed in the B

horizons. Observed effects of alder on acidity and base content disagree with the generally held concept of hardwoods as base conservers. These effects may indicate greater production of acid decomposition products in the organic- and nitrogen-richer alder soils." (A)

181. Franklin, Jerry F., and Anna A. Pechanec.

1968. Comparison of vegetation in adjacent alder, conifer, and mixed alder-conifer communities. I. Understory vegetation and stand structure. In *Biology of alder*, p. 37-43. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Vegetational analyses of adjacent 40-year-old coastal Oregon stands of red alder, conifers, and mixed alder-conifer showed marked differences in coverage and richness of understory. Shrubby species were confined mainly to the pure alder stand, where they formed a dense layer. Herbaceous plants were best developed in the alder mixed stands and ground-dwelling cryptogams in the mixed and conifer stands. Differences in canopy density, and, perhaps, in nutrition probably accounted for most of the contrasts. Although current regeneration of trees was uniformly absent, suppressed Sitka spruce saplings persisting in the alder and mixed stands could, by responding to future release, partially replace a deteriorating alder over-story." (A)

182. Friedman, Janet Patterson.  
1975. The prehistoric uses of wood at the Ozette archaeological site. Ph. D. thesis. Wash. State Univ., Pullman. 262 p.

"As a result of the remarkable preservation situation available at the Ozette Archaeological Site in Northwestern Washington State, working in wood, generally considered the major technological component of Northwest Coast culture, can be studied in an archaeological context. The current study deals with the identification of wood species utilized in the manufacture of specific categories of wooden artifacts by these aboriginal people. Evidence indicates that they selectively utilized a wide range of available woods, choosing the species with mechanical and other properties best suited to the needs posed by a particular type of artifact. They were well aware of the potentialities of their environment, and utilized it knowledgeably." (A)

183. Fritz, Emanuel.

1945. Twenty years' growth on a redwood sample plot. J. For. 43(1):30-36.

"A 1-acre sample plot of 85-yr.-old Sequoia sempervirens on a high site 1, on which growth data have been recorded for 20 yrs., shows the phenomenal yield of 223,034 board ft., not including an additional 21,400 board ft. accretion on 5 old-growth residual redwoods and a small amt. of Alnus oregonia. During the decade when the stand was betw. 65 and 75 yrs. old, the periodic annual growth exceeded 5,000 bd. ft. per acre." (BA)

184. Froidevaux, Lucien.  
1973. The ectomycorrhizal association, Alnus rubra + Lactarius obscuratus. Can. J. For. Res. 3(4):601-603.

"A laboratory study was made of samples of roots of A. rubra and sporocarps of L. obscuratus both collected in the Coast Ranges of western Oregon. The mycorrhizal association was confirmed by comparing the mycorrhizal mantle with the mycelium at the base of the stipe of the sporocarp for morphology, reaction to chemical reagents, and auto-fluorescence in long-wave ultraviolet light." (FA)

185. Froidevaux, Lucien.  
1975. Aureobasidium pullulans (de Bary) Arnaud: An associate of Alnus rubra and Lactarius obscuratus mycorrhizae. Eur. J. for. Pathol. 5(2):124-127.

"A. pullulans was isolated from 50% of A. rubra and L. obscuratus mycorrhizae collected in western Oregon in Nov. 1972. In laboratory tests, A. pullulans had an inhibitory effect on the growth of the root pathogen Fusarium oxysporum." (FA)

186. Furlow, John Jacob.  
1974. A systematic study of the American species of Alnus (Betulaceae). Ph. D. thesis.  
Mich. State Univ., Lansing. 503 p.

"The genus Alnus consists of about 20 species of shrubs and trees, mainly of the Northern Hemisphere, but extending below the Equator into South America along the Andes. Although a wide array of studies of the genus during the past 70 years have produced an abundance of new data, and this period has seen the

development of different philosophies concerning taxa in general, there has been no comprehensive revisionary effort in that time. Consequently current treatments of Alnus suffer from a lack of up-to-date information and unified taxonomic concepts. The species are often variable, and this had led to both widespread confusion in the treatment of taxa and a proliferation of infraspecific and specific names. In addition, where the geographical ranges of taxa overlap, the plants appear to hybridize readily, adding to the problems of identification and classification.

"From the results of the palynological, anatomical, chemosystematic, and numerical taxonomic studies, as well as ordinary observation, it is seen that the American taxa of Alnus group into three major clusters, which are treated as subgenera (Alnus, Alnobetula, and Clethropsis). Four taxa are regarded as conspecific with Eurasian Alnus incana subsp. rugosa, A. incana subsp. tenuifolia, A. viridis subsp. crispa, and A. viridis subsp. sinuata). The Latin American taxa are shown to comprise two species, Alnus acuminata and A. jorullensis, each of which is subdivided into two varieties (A. acuminata var. acuminata and A. acuminata var. glabrata on the one hand, and A. jorullensis var. jorullensis and A. jorullensis var. firmifolia on the other).

"Subgenera Clethropsis and Alnobetula are represented by single species in America (Alnus maritima and A. viridis, respectively). Subgenus Alnus is composed of two or more less distinct groups of taxa, one represented by the shrubby northern A. incana and A. serrulata, and the other by the Latin American species and the large tree species of the northern and central sections of the western part of the continent (Alnus rubra, A. rhombifolia, and A. oblongifolia). The latter group is regarded as the most primitive segment of the genus in the New World." (A)

187. Fye, Calvin G., and David G. Briggs.

1978. A comparison of lumber grading rules for alder and competing species. In Utilization and management of alder, p. 85-92. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"This paper contains a comparison of lumber grading rules and practices for red alder and competing species in the hardwood lumber trade such as birch, yellow poplar, soft maple, and black cherry." (A)

188. Gara, R. I., and L. L. Jaeck.

1978. Insect pests of red alder: Potential problems. In Utilization and management of alder, p. 265-269. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Although insect problems of red alder receive little attention at present, concern about insect damage will increase with increasing value and management of the species. Tent caterpillars and saw-flies appear to offer the most serious threats to intensive management; defoliation by these insects could lead to drastic reductions in growth of heavily infested stands. Chrysomelid beetles, such as the alder flea beetle, can also be destructive as both larval and adult stages defoliate alder. Bark beetle populations are normally low and damage is limited; however, increased harvest,

if accompanied by large amounts of logging slash, could result in population build-up and subsequent attack and mortality of trees in residual stands. Ambrosia beetles attack down logs and can degrade lumber unless removal and utilization proceeds promptly after felling." (A)

189. Garman, E. H.

1953. Pocket guide to the trees and shrubs of British Columbia. B.C. For. Serv. Publ. B. 28, 102 p. Victoria, B.C.

190. Gerhards, C. C.

1964. Limited evaluation of physical and mechanical properties of Nepal alder grown in Hawaii. USDA For. Serv. Res. Note. FPL-036, 4 p. For. Prod. Lab., Madison, Wis.

"Hawaii-grown Alnus nepalensis, tested for (a) shrinkage, (b) bending strength, and (c) hardness, was found to equal samples from Bengal in (b), and to exceed them in (a) and (c). Its modulus of elasticity (m.e.) was lower. It was harder than U.S.-grown Populus tremuloides and Pinus ponderosa, but softer than Alnus rubra. It was comparable to P. tremuloides in (b), but lower in m.e. Values for (a) in the radial and tangential directions were lower than in A. rubra and only slightly greater than in P. tremuloides and Pinus ponderosa." (FA)

191. Gessel, S. P., T. N. Stoate, and K. J. Turnbull.  
1965. The growth behavior of Douglas-fir with nitrogenous fertilizer in western Washington. Coll. For. Resour. Bull. 1, 204 p. Univ. Wash., Seattle.

"A very detailed report (119 tables, 28 graphs, 17 maps) of the lay-out and results to date (1962) of long-term study, initiated 15 years previously, to investigate the effects of artificial fertilizers on immature Douglas Fir in western Washington. N has been the one actively simulating element so far discovered; its effects on crown size, height, diameter, volume, foliage, and soil are dealt with. No attempt has been made to determine the forms and amounts of N required to produce any effect, or the economics of fertilizing. An important interaction between weight of fertilizer and site quality resulted in greater additional gross increment per unit N on poor than on good quality classes." (FA)

192. Gessel, S. P., T. N. Stoate, and K. J. Turnbull.  
1969. The growth behavior of Douglas-fir with nitrogenous fertilizer in western Washington. The second report. Univ. Wash. Inst. For. Prod. Contrib. 7, 119 p. Seattle, Wash.

A highly variable, improved growth rate differing between locations generally results from the application of nitrogen fertilizer to second-growth Douglas-fir forests. The reason for the variation is unknown. (CFH)

193. Gessel, S. P., and J. Turner.  
1974. Litter production by red alder in western Washington. For. Sci. 20(4):325-330.

"Litter production was measured with four 45.7<sup>2</sup> cm traps per stand for 8 to 9 years in seven 30-year-old red alder (Alnus rubra Bong.) stands. Production between years did not differ significantly except for one in which buds and twigs were severely damaged by frost the previous November. The wetness of the summer in a given year affected timing and amplitude of the annual production peak. Annual nitrogen return was from 80 to 200 kg ha<sup>-1</sup> yr<sup>-1</sup>." (A)

194. Gessel, S. P., and John Turner.  
1973. Litter production by stands of red alder in western Washington. Coniferous For. Biome Intern. Rep. 57, 6 p. Univ. Wash., Seattle.

195. Gessel, Stanley P., Kenneth J. Turnbull, and F. Todd Tremblay.  
1960. How to fertilize trees and measure response. 67 p. Natl. Plant Food Inst., Washington, D.C.

Gives a site index curve for red alder. (CFH)

196. Glendenning, R.  
1928. An interesting Myzocallis (Homoptera, Aphididae). Entomol. Soc. B.C. Proc. 1928(25):18-20.

"M. alni DeGeer was found by the author on 2 widely separated host plants, native alder (Alnus oregona) and wild strawberry (Fragaria glauca)."  
(BA)

197. Glennie, Douglas W., and John S. Mothershead.  
1964. Chemical structure of lignin sulfonates. I. Preparation of lignin sulfonates from red alder. *Tappi* 47(6):356-360.

"Hardwood lignin was treated under moderate conditions so as to prepare lignin sulfonates for isolating and identifying monomeric and dimeric components. A 17.3-lb. sample of extractive-free wood chips from the outer 10-year growth of a red alder bolt was cooked with aqueous sodium bisulfite in three separate and successive stages of increasing temperature. Pulp of wood quality was obtained in 49.9% yield with a calculated removal of lignin of 86.7%. Comparison of the ultraviolet absorption characteristics for vinylvanillyl and vinylsyringyl sulfonates indicated that for every two guaiacyl units there were present about three syringyl units in red alder lignin sulfonates. Similarly, one unit in three was estimated to contain a free phenolic hydroxyl group. Since lignin sulfonates obtained in the first bisulfite cooking stage were prepared under moderate conditions for sulfonation and came by diffusion from extractive-free chips from uniform wood of recent growth, they were considered a suitable source for isolation of derivatives with low molecular weights that resemble protolignin in red alder." (A)

198. Gordon, John C.  
1978. Biological components of alder yield improvement. In *Utilization and management of alder*, p. 321-325. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Although alder has not been extensively used in intensive forestry, its potential is great. Two species, *Alnus rubra* Bong. and *Alnus glutinosa* (L.) Gaertn., are particularly promising because of their growth habit, characteristics, and having been studied more than other alders. The concept of ideal plant type, or ideotype, is useful in determining the yield potential and the need for improvement in specific characteristics of crop plants.

When alders are compared to an ideotype for maximum yield of fiber, they fit well--rapid juvenile growth, ease of vegetative propagation, crown shape, growing season utilization, nitrogen fixation, microbiological relations, genetic variation, and early flowering are all positive. Characteristics with poorer fit are water relations, unit-leaf-area rate of photosynthesis, fecundity, and wood properties. These, however, are susceptible to some genetic and cultural improvement. Recent studies have shown, for example, that photosynthetic capacity and the ability to fix atmospheric nitrogen are closely related but that considerable genetic variation exists in both characteristics." (A)

199. Gordon, John C., and Richard B. Hall.  
1978. Alder research outside the Northwest: A brief overview. In Utilization and management of alder, p. 47-53. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Over the past century Europeans have done much cultural and physiological research on Alnus glutinosa. Black alder has also been studied and used extensively in Europe and the Eastern United States for land reclamation. Most physiological research on black alder has been related to its capability to fix nitrogen symbiotically, although some data on photo-synthesis and translocation are available. Other European alder species that have received attention are Alnus incana and Alnus cordata. The Netherlands, Germany, Sweden, Finland, and Great Britain have alder genetics or tree improvement programs at one or more locations. Most of the cultural studies have had as their objective the increased use of black alder as an intercrop or rotation crop with conifers or poplars. In Great Britain there is renewed research interest in Alnus rubra, as a windbreak species for the protection of conifer plantations, and as an amenity tree." (A)

200. Graf, Phillip Edward.  
1974. Successional stages of red alder in Bonner County, Idaho. M.S. thesis. Univ. Idaho, Moscow. 146 p.

"In northern Idaho seral populations of Alnus rubra are disjunct from the major populations located west of the Cascade-Sierra axis. My objective was to provide a synecological description of plant communities associated with Alnus rubra,

especially the seral stages which are dominated by Alnus rubra, and the resulting climax association which lacks Alnus rubra. Thus, a study of Alnus rubra habitats around Lake Pend Oreille showed that both Thuja plicata and Tsuga heterophylla are climax dominants. All of the Alnus rubra successional stages sampled are on potential Tsuga heterophylla climax sites. The under-story is dominated by the Pachistima myrsinites vascular union, with a dominance of Polystichum munitum beneath the successional stands of Alnus rubra. Early successional stages are dominated by pure Alnus rubra. Early successional stages are dominated by pure Alnus rubra. Potential climax plants are soon established beneath the Alnus overstory. Later in the sere, Tsuga heterophylla gradually overtakes Alnus rubra, and near climax only dead Alnus rubra individuals are present in the stand. In contrast to the Lake Pend Oreille area, other areas, with disjunct populations, further south in northern Idaho were not glaciated. This has resulted in less disjuncts and endemics occupying the Lake Pend Oreille area." (A)

201. Graham, R. D.  
1954. Vapor drying of western woods. Oreg. For. Prod. Lab. Rep. D-2, 11 p. Oreg. State Univ., Corvallis.

"Detailed results for Douglas Fir (1-, 2-, and 4-in.) and Western Hemlock (2-in.) and preliminary results for Redwood, Pacific madrone, Red Alder and Ponderosa Pine are tabulated." (FA)

202. Graham, Robert D., and Donald J. Miller. 1963. Service life of treated and untreated fence posts: 1963 progress report on the post farm. Oreg. For. Prod. Lab. Prog. Rep. 13, 24 p. Oreg. State Univ., Corvallis.

Information on the expected useful life of fenceposts. Red alder is one of the species evaluated. Similar information can be found in earlier reports in this series. (CFH)

203. Gram, K., C. Muhle Larsen, C. Syrach Larsen, and M. Westergaard. 1941. Contributions to the cytogenetics of forest trees. II. Alnus studies. K. Vet. Højsk. Arsskr. 1941:44-58. Denmark, Copenhagen.

"Alnus glutinosa, A. incana, A. hirsuta, A. tenuifolia, A. tenuifolia var. occidentalis, A. rubra, and A. cordata had  $2n = 28$  chromosomes. Trees cultivated under the names A. subcordata, A. japonica, and A. orientalis had  $2n = 42$ , and in one individual of A. subcordata  $2n = 56$ . Meiosis was regular in the diploids, very irregular in the triploids, and regular--apart from the formation of some few tetrasomes--in the tetraploid A. subcordata. The triploids are regarded as hybrids between diploid and tetraploid species, and triploids cultivated in various botanical gardens under species names are evidently spontaneous hybrids grown under the name of the mother tree. According to other authors, A. japonica and forms of A. glutinosa are also tetraploid, as is A. subcordata X A. glutinosa (A. spaethii). Experimentally produced hybrids are listed. (FA)

204. Gramovsky, A. A. 1928. A review of myzocallis species inhabiting Alnus, with description of a new species (Homoptera, Aphiidae). Ann. Entomol. Soc. Am. 21(4):546-565.

"Keys to 4 spp. of Myzocallis inhabiting Alnus, alate and apterous viviparous and apterous oviparous ♀♀, and alate ♂♂. Redescriptions of M. alni, alate\* and apterous \* viviparous ♀♀, apterous oviparous ♀ \*, alate ♂ \* which is known in America only from Illinois, Oregon, and British Columbia, M. alnifoliae, the same stages\*, on Alnus incana, A. rubra, A. rugosa, and A. serrulata in eastern United States; M. rhombifoliae (p. 555), same states\*, from Alnus rhombifolia and A. incana, Wisconsin (type) and California; M. pseudoalni, alate viviparous ♀ \*." (BA)

205. Gratkowski, H., D. Hopkins, and P. Lauterbach. 1973. The Pacific coast and northern Rocky Mountain region. J. For. 71(3):138-143.

Discusses brush control in the Pacific coast and Rocky Mountain areas. (CFH)

206. Graves, Henry S. 1912. Red alder. Alnus oregonia Nutt. U.S. Dep. Agric. Silvical Leafl. 53, 4 p.

207. Gregson, P. G. 1948. The management and utilization of red alder. B.S.F. thesis. Univ. B.C., Vancouver. 59 p.

208. Grobey, John Henry.  
1964. An economic analysis of the hardwood industry of western Washington. M.F. thesis. Univ. Wash., Seattle. 101 p.
- Although part of the national hardwood industry, the hardwood industry of Washington is considered on a regional basis. Growth is expected but at present it is underutilized. Important reasons are interaction with other segments of the local timber industry, imperfections in the competitive behavior of resource markets, and certain institutional factors. (CFH)
209. Grondal, Bror L.  
1918. Seattle shoe factory utilizes red alder. West Coast Lumberman 34(398):21.
- Describes a manufacturing process which uses seasoned red alder as soles for wooden shoes. (CFH)
210. Grondal, Bror L.  
1956. New process barks alder. Pulp and Pap. 30(3):125-126.
- Alder bark is almost completely cooked away in the pulping process, yielding little pulp but requiring additional cooking liquid and decreasing digester capacity. Fresh green chips will float in water while bark particles sink. Chips with adhering bark will either float or sink depending on the amount of bark present. A proposed cleanup scheme involves screening to remove fines, rolling to loosen bark, and finally, a flotation to separate chip and bark. (CFH)
211. Grondal, Bror L., and Piotr Zenczak.  
1949. Prolysis of wood: Recent developments. Trend Eng. Univ. Wash. 1(2):23-25. Seattle, Wash.
- "Describes small-scale prolysis experiments carried out for checking claims put forward by Slavyansky. Attempts at improving the process of distilling the wood, while immersed in kerosene, under different temperatures and pressures, resulted in obtaining a high proportion of soluble tar and of acetic acid. Experiments were carried out with Douglas Fir heartwood in the form of large and small blocks and sawdust, and with Red Alder blocks. Kerosene losses were negligible. The charcoal obtained presents a very extended interior surface area." (FA)
212. Gunther, Erna.  
1945. Ethnobotany of western Washington. Univ. Wash. Publ. Anthropol., 61 p. Seattle.
- Uses of plants by native Americans. (CFH)
213. Haard, Richard T.  
1971. The periodicity of spore release from a conifer, a liverwort, and a bracket fungus. Northwest Sci. 45(3):183-187.
- "Two Kramer-Collins air samplers were used to observe hourly pollen release from a tree of Tsuga heterophylla in Mt. Baker National Forest, Wash., at 3500 ft alt. for 10 days in May, 1968. Well defined peaks in pollen release, coinciding with the lowest daily r.h. (29-43%) were noted on May 9, 10 and 11. Thuja plicata and Alnus rubra, growing at ca. 500 ft alt. in the same county, showed similar

patterns of pollen release. At the Mt. Baker site, parallel observations were made on spore release from a liverwort and from the fungus Ganoderma applanatum; the patterns for these differed inter se and from the pattern of pollen release in T. heterophylla." (FA)

214. Haddock, Philip G.  
1949. A problem child reforms:  
New perspectives in the management  
of red alder. For. Club. Q.  
22(2):9-15. Univ. Wash., Seattle.

"A review of the existing literature on the management and utilization of Alnus rubra in the Pacific Northwest, where it is the most plentiful and useful hardwood species." (FA)

215. Hagman, M.  
1975. Incompatibility in forest  
trees. R. Soc. London Proc. B.  
188, p. 313-326.

"Despite the great importance for forest tree breeding, very limited knowledge is yet available about the breeding systems of forest trees. Where incompatibility has been studied in the hardwoods; patterns have been observed which confirm the general rules detected for other angiosperms. Self- and interspecific incompatibility at the level of pollen tube growth has been reported for example in Betula and Alnus. In Alnus one case of unilateral interspecific incompatibility has been found. Self-incompatibility has, so far, not been reported from the conifers. Interspecific incompatibility in the form of the arrestment of the pollen tube growth in the nucellus tissue has been observed in Picea and is particularly clear in Pinus crosses between the subgenera Haploxyylon and Diploxyylon, but also within the Diploxyylon-group. The

nature of the incompatibility mechanism is still unknown, but serological differences related to the behaviour in the crosses had been detected in birch and pine pollen. It is suggested that the complex polysaccharidic composition of the cell walls and membranes might form a specific stereochemical basis for the incompatibility reaction. The presence of a combination of self-pollination, polyembryony and genetic load is discussed as an alternative mechanism favouring outbreeding in the Gymnosperms." (A)

216. Hagman, Max.  
1967. Genetic mechanisms affecting inbreeding and outbreeding in forest trees; their significance for micro-evolution of forest tree species. Int. Union. For. Res. Organ. 14th Congr. Proc., Munich, Pt. III, Sect. 22, p. 346-365.

"Reviews past studies on incompatibility in plants in general and forest species in particular. The author has observed that self-incompatibility in some species of Betula and Alnus is due to a retardation in the growth of the pollen tube. The influence of these factors in the micro-evolution of species is discussed." (FA)

217. Hall, J. Alfred.  
1969. The pulp and paper industry and the Northwest. 61 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Discusses red alder as an unused or a little-used species in the pulp and paper industry. (CFH)

218. Hall, J. Alfred.  
1970. Wood, pulp and paper, and  
people in the Northwest. 34 p.  
Pac. Northwest For. and Range Exp.  
Stn., Portland, Oreg.

Discusses alder as an unused or a little-used species in the pulp and paper industry. (CFH)

219. Hall, John W.  
1950. The comparative anatomy of  
the Betulaceae. Am. J. Bot.  
37(8):662.

"Anatomical evidence indicates that the Betulaceae are not primitive, but are moderately specialized. The trends of specialization are: in the Butuleae, from Alnus (scalariform perforation plates with numerous narrow bars; opposite and alternate intervacular pitting) to Betula (reduction in the number of bars and widening of the bars in the perforation plates; exclusively alternate intervacular pitting); thence in the tribe Coryleae to Corylus and Ostryopsis (spiral thickenings in the vessels; fibre-tracheids exclusively; reduced number of wide bars in the scalariform perforation plates; heterogeneous rays) to Carpinus (marked tendency toward simple perforations; homogeneous rays) and to the most advanced genus, Ostrya (simple perforations; homogeneous rays etc.)." (FA)

220. Hall, John W.  
1952. The comparative anatomy and  
phylogeny of the Betulaceae. Bot.  
Gaz. 113(3):235-270.

Twenty-four species of Alnus were studied. Only three of the four sections of the genus are represented. The wood anatomy of the Betulaceae was studied

comparatively to establish the phylogenetic position of the family. The Betulaceae is more primitive than the Coryleae. Alnus is less specialized than Betula. (CFH)

221. Hamilton, J. K., and N. S. Thompson.  
1958. A comparison of the carbohydrates of hardwoods and softwoods. Pulp & Pap. Mag. Can.  
59(10):233-241.

"Holocelluloses have been prep'd. from a no. of hardwoods and softwoods by the chlorite method and, in certain instances, by a new milder method employing  $\text{ClO}_2$  buffered to pH 7. Western red alder has been shown to contain a glucomanan (I) with glucose:mannose = 2:3. The isolation and identification of cryst.  $0-\alpha-4-O\text{-methylglucuronopyranosyl-(1}\rightarrow 2)-O\text{-B-D-xylopyranosyl-(1}\rightarrow 4)\text{-D-xylopyranosyl-trihydrate}$  indicates that the 4-O-methylglucurono-xylan (II) of this wood is similar to that from other hardwoods. The results of pretreatment and high-strength NaOH extns. of various holocelluloses indicate that most of the hemicelluloses are not chemically combined with the cellulose of either type of wood. Though the cellulose of the hardwoods and softwoods are similar in phys. and chem. properties, it would appear that their noncellulosic polysaccharides have several differences. Hardwoods contain 20-30% hemicelluloses, consisting mostly of II with a high ratio of D-xylose (II) to 4-O-methyl-D-glucuronic acid (IV) and small amts. of glucose, arabinose, and mannose which last appears to be assoacd. with a highly inaccessible I. Softwoods contain 15-20% hemicelluloses consisting mostly of a difficulty extractable I, small amts. of 4-O-methylglucuronoxylan having a lower ratio of III to IV, and to a lesser but significant extent sol. I, galactoglucomannans, and arabogalac-

tans. Traces of rhamnose and glucuronic acid occur in both hardwoods and softwoods." (BA)

222. Hamilton, J. K., and N. S. Thompson. 1959. A comparison of the carbohydrates of hardwoods and softwoods. *Tappi* 42(9):752-760.

"Compares the hemicellulose of hardwoods (mainly Alnus rubra, Arbutus menziesii, Liquidambar styraciflora, Nyssa aquatica and N. sylvatica), and of softwoods (Tsuga heterophylla, Thuja plicata, Pinus elliottii, P. palustris, etc.), and presents detailed tabulated results of research on the behavior of hemicelluloses during various pulping processes. These results indicate that the residual extraction-resistant sugars which remain associated with the cellulose as shown by hydrolysis, are not part of the cellulose but are due to inaccessible or highly insoluble polymers intimately associated with it." (FA)

223. Hansen, Everett.

1975. Phellinus (Poria) weiri root rot in Douglas-fir-alder stands 10-17 years old. USDA For. Serv. Res. Note PNW-250, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Red alder growing in even-aged mixture with Douglas-fir did not reduce initial losses to Phellinus weiri 10- to 17-year-old Douglas-fir plantations. The ability of alder to reduce later losses from lateral spread within the stand was not examined. P. weiri is creating openings in these young stands with 3 percent of the trees already dead in one case. The symptoms and distinguishing features of P. weiri infection on young trees are described." (A)

224. Hansmann, Eugene W., and Harry K. Phinney. 1973. Effects of logging on periphyton in coastal streams of Oregon. *Ecology* 54(1):194-199.

"Describes part of a study on small catchments, comparing the effects of clear felling and patch logging on the water quality and biological resources of small coastal streams. The overstorey on the catchments consisted mainly of Pseudotsuga menziesii and Alnus rubra." (FA)

225. Harger, J. R. E.

1973. Damage to vegetation by chlorine gas. *Int. J. Environ. Stud.* 4:93-108.

"The effects of chlorine gas emanating from a factory in causing damage to foliage were tested on Malus fusca, Populus trichocarpa, Rubus spectabilis, Alnus rubra and Sambucus racemosa var. arborescens. S. racemosa was the most susceptible species. (FA)

226. Harrar, E. S.

1958. Hough's encyclopaedia of American woods. Vol. 2, 223 p. Robert Speller & Sons, New York.

Volume 2 of 16 volumes on properties and uses of American woods. Includes botanical description of trees, leaves, flowers, and fruits. Gross diagnostic features, microscopy, and tables of physical properties of wood are presented. An accompanying atlas volume includes thin section samples of wood in radial, tangential, and transverse cuts. (CFH)

227. Harris, Arland S., and Wilbur A. Farr.

1974. The forest ecosystem of southeast Alaska. 7. Forest ecology and timber management. USDA For. Serv. Gen. Tech. Rep. PNW-25, 109 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Large-scale use of the timber resource of southeast Alaska began in 1953 after long efforts to establish a timber industry. Development and present status of the industry and present management of the timber resource are summarized, stressing the biological basis for timber management activities in southeast Alaska today. Ecological and silvicultural considerations related to timber harvest, reforestation, and stand development are discussed.

"Published and unpublished information are brought together. Current management practices are discussed as a basis for better understanding of how this information can be helpful in managing the timber resource and to point out where research is needed." (A)

228. Harris, K. F.

1950. Growing good quality second growth alder. B.C. Lumberman 34(7):41, 109-110, 112.

Suggests modifications of European silvicultural techniques that may be applicable to intensive management of red alder. Gives estimates, in time per acre, of various silvicultural treatments. (CFH)

229. Hartman, David A., William A. Atkinson, Ben S. Bryant, and Richard O. Woodfin.
1975. Conversion factors for the Pacific Northwest forest industry: Converting forest growth to forest products. 112 p. Inst. For. Prod., Coll. For. Resour., Univ. Wash., Seattle.

A collection of tables of wood yield expressed in cubic measurements. English and metric units are presented. (CFH)

230. Hatton, J. V., and K. Hunt.

1977. Physical properties of softwood and hardwood kraft pulps as a function of bulk. Tappi 60(10):145-147.

"Data presented substantiate earlier findings that bulk (specific volume) can be used in place of the Canadian standard freeness (CSF) test to characterize pulp physical properties. Linear regression equations were found for kraft pulps of balsam fir, tamarack, red alder, beech, yellow birch, and maple, which correlate wide ranges of bulk with CSF values for burst factor, breaking length, and tear factor. It was observed that quadratic equations would fit the data slightly better. Areas of caution are indicated which should be considered before replacing CSF tests by bulk determinations." (FA)

231. Hatton, John V.

1976. The potential of process control in kraft pulping of hardwoods relative to softwoods. Tappi 59(8):48-50.

"Application of three-equation sets of general form  $(Y, P, K) = A - B [(\log H)(EA)^n]$ , to kraft pulping data from three softwood species--alpine fir, balsam fir, and Douglas fir--and four

hardwood species--beech, hard maple, red alder, and yellow birch--revealed that in hardwood kraft pulping, process control will be more difficult to achieve than for softwoods under normal operating conditions. In these equation sets, the three output variables--total pulp yield (Y), screened-pulp permanganate number (P), and screened-pulp kappa (K)--are related to the two major kraft pulping input variables of H-factor (H) and effective alkali applied (EA). A consistent behavioral pattern observed within the three-equation sets for softwoods, pulped under a variety of kraft processing conditions, is confirmed by relatively high values of  $r^2$ , a measure of the goodness of fit of the derived equations with the experimental data. Thus, process control for kraft mill processing of softwoods should be relatively straightforward. For hardwoods, however, with their more variable chemical composition, less consistency is observed within the three-equation sets, and the derived equations do not fit the experimental data as well as for the softwoods." (A)

232. Hawkes, Carl.  
1953. Planes release tree plantation. J. For. 51(5):345-348.

"Describes successful operations in Oregon for the release of 10-year-old conifer plantations from Red Alder by spraying from the air with 2,4-D at the rate/acre of 2 lb. acid equivalent mixed with 8 gal. water and 2 oz. sticker-spreader. Cost of spraying 1000 acres was \$5-15/acre. Alder was killed, Willow discouraged, and little damage done to the other trees and shrubs." (FA)

233. Hawley, L. F., and Louise E. Wise.  
1926. The chemistry of wood.  
334 p. Chem. Cat. Co., Inc.,  
New York.

Tables on volume and analysis of red alder. (CFH)

234. Hayes, James.  
1948. Utilizing hardwoods from the farm. 27th Annu. Wash. State For. Conf. Proc., p. 20-22. Seattle, Wash.

235. Heebink, T. B.  
1965. Suitability of seven west coast species for pallets. USDA For. Serv. Res. Pap. FPL-22, 16 p. For. Prod. Lab., Madison, Wis.

"Describes tests of different types of pallet made from (1) Pseudotsuga taxifolia, (2) Tsuga heterophylla, (3) Lithocarpus densiflorus, (4) Larix occidentalis, (5) Pinus ponderosa, (6) Populus trichocarpa and (7) Alnus rubra, for resistance to (a) bending under load, (b) distortion when dropped on a corner, and (c) damage when thrown about in a revolving drum. The performance of (2) was as good as (1) throughout, that of (5), (6), and (7) was as good as (1) for (b) and (c) but inferior for (a), and (3) and (4) were inferior to (1) in all respects. Comparative tests of pallets of (1), (2) and (7) made from dry and green lumber were inconclusive." (FA)

236. Henderson, J. A.  
1970. Biomass and composition of the understory vegetation in some Alnus rubra stands in western Oregon. M.S. thesis. Oreg. State Univ., Corvallis. 64 p.

237. Hepting, George H.  
1971. Diseases of forest and shade trees of the United States. U.S. Dep. Agric. Agric. Handb. 386, 658 p. Washington, D.C.

This book discusses the pathology of trees native to the United States and of many species introduced for shade and ornamental purposes. It describes the main characteristics of a tree and its pathogens, then lists materials and references helpful to a person diagnosing diseases of a species. (CFH)

238. Herfeld, H., and E. Zieger.  
1951. Fichten-, Kiefern- und Erlenzapfen als Gerbmaterialien. [Spruce, pine, and alder cones as tanning materials.] Gesammelte Abh. Dtsch. Lederinst., Freiberg, Germany, No. 6, p. 65-75.

"Results of an investigation into the tannin content of Spruce cones, both fallen and gathered from the trees; various portions of Spruce cones and Pine and Alder cones; with tables on results of extraction of Spruce and Alder cones, and of compatibility tests of Spruce-cone extracts with vegetable and synthetic tanstuffs. In this respect Pine cones were found to be of little value, but cones of Spruce and Alder (Alnus glutinosa, A. incana, A. rubra) could be advantageously used in the tanning industry." (FA)

239. Hetherington, J. C.  
1964. Brush control in coastal British Columbia. B.C. For. Serv. Res. Note 38, 56 p. Vancouver.

"A summary of the principles of chemical, mechanical, and biological methods of brush control and the results of a study based on the examination of a large number of commercial and experimental brush-control projects in British Columbia. The control of Alnus rubra, Acer macrophyllum, A. circinatum, Rubus spectabilis, Pteridium aquilinum, and Gaultheria shallon by chemical means is discussed. Mechanical removal of brush by bulldozer, by girdling, and by cutting, and the silvicultural characteristics of tree species planted in brush areas are also considered. When possible, costs are given for all treatments." (FA)

240. Heusser, C. J.  
1969. Modern pollen spectra from the Olympic Peninsula, Washington. Bull. Torrey Bot. Club 96(4):407-417.

"In samples from 52 sites in different sectors and altitudinal zones between sea-level forest and alpine tundra, pollen of Tsuga heterophylla and Alnus rubra was dominant. Extra-zonal pollen constituted part of the deposits. Variation within a zone was due to disturbance such as logging, fire, etc. The value of the data for interpreting N. Pacific Pleistocene pollen profiles is discussed." (FA)

241. Heusser, C. J.  
 1974. Quaternary vegetation climate and glaciation of the Hoh River Valley, Washington. Geol. Soc. Am. Bull. 85(10):1547-1560.
- "The Hoh River valley, on the west side of the Olympic Peninsula, is about 90 km long and is one of the major valleys originating in the interior Olympic Mountains [USA]. Pollen stratigraphy and  $^{14}\text{C}$  chronology of 3 bog cores in the lower Hoh valley show tundra at low elevations from  $18,800 \pm 800$  yr B.P. until about 10,000 yr B.P. Holocene-vegetation is portrayed by 3 pollen assemblages: *Pinus-Alnus-Picea-Pseudotsuga-Pteridium* (10,000 to 8000 yr B.P.), *Picea-Tsuga-Alnus-Pseudotsuga-Pteridium* (8000 to 3000 yr B.P.) and *Tsuga-Thuja-Abies* (3000 to 0 yr B.P.). The sequence implies a climatic trend from a cool and relatively humid climate in the beginning, to increasing warmth, then maximum warmth and lower humidity, and finally to a cooler and quite humid climate at the close. The sequence also reflects the gradual replacement of open, successional forest communities by a late Holocene-age closed rain forest. Pollen influx is low, generally less than 1500 grains  $\text{cm}^{-2} \text{ yr}^{-1}$ , except around 8000 yr. B.P., when values exceeded 5000  $\text{cm}^{-2} \text{ yr}^{-1}$ . Traces of tephra from the eruption of Mount Mazama, found in 1 bog section, mark an extreme Pacific continental limit for this ejectamenta. Refugia on the Olympic Peninsula contained the stock from which major migrations of plants northwestward along the north Pacific coast took place toward the close of Fraser Glaciation and during Holocene time." (BA)
242. Heusser, Calvin J.  
 1960. Late-Pleistocene environments of north Pacific North America. Am. Geogr. Soc. Spec. Publ. 35, 308 p.
- A comprehensive discussion of the vegetation, environment, and chronology of the Pacific coast of North America from the late Pleistocene (about 14,000 years ago) to the present. Red alder was an important successional component of the region during this period. (CFH)
243. Heusser, Calvin J.  
 1973. Environmental sequence following the Fraser advance of the Juan de Fuca lobe, Washington. Quat. Res. 3(2):284-306.
- "Stratigraphic palynology and radiocarbon chronology of two bogs and a lake on the northwestern Olympic Peninsula serve to record the environmental sequence post-dating the Fraser maximum of the Juan de Fuca lobe. Wastage of the lobe in the terminal area began before  $14,460 \pm 200$  BP. Differential downwasting followed, and the last remnants of dead ice probably disappeared some time before  $9,380 \pm 180$  BP. Ablation margin became sufficiently thick in the course of wastage for a vegetation cover to become established. Arboreal remains of this cover, found buried in till, date between  $12,020 \pm 210$  and  $13,380 \pm 250$  BP.
- "Communities of *Pinus contorta* first succeeded on deglaciated surfaces during the Vashon Stade. Environmental conditions were comparable to those prevailing in the modern subalpine forest, and average July temperature stood near  $12^\circ\text{C}$ . Later, during the Everson Interstade (11,000-13,000 BP.), *Alnus* and *Picea* multiplied as temperature increased possibly to as much as  $14^\circ$ . During the Sumas Stade (10,000-11,000 BP.), temperature was again ca.  $12^\circ\text{C}$ , the cooler climate halting wastage and the spread

of Alnus and enabling communities of Picea, Tsuga heterophylla, and T. mertensiana to temporarily achieve stability.

"Postglacial environments through the Hypsithermal (ca. 3,000 BP) were dominated principally by Alnus. Alnus, succeeded in turn by Picea, invaded the landscape, following the recession of alpine glaciers and the rise in elevation of the snowline. For a time, as suggested by a peak of Pseudotsuga, temperature may have reached close to 17° and annual precipitation less than 760 mm. Arboreal communities were relatively open while light-requiring Pteridium remained conspicuous in the record. After 3000 BP during Neoglaciation, climate became sufficiently cool and moist to favor the development of extensive, closed communities of Tsuga, Picea, Thuja, and other hygrophilous species." (A)

244. Hewitt, E. J., and G. Bond.

1966. The cobalt requirements of non-legume root nodule plants. *J. Exp. Bot.* 17(52):480-491.

"Experiments with Casuarina cunninghamiana, Myrica gale and Alnus glutinosa confirmed the necessity of Co for proper growth of nodulated plants. Under the conditions of the experiment, marked N-deficiency symptoms appeared during the second growth season when Co was not supplied. The need for Co appears to be confined to the nodules. The relationship between the presence of Co, vitamin B<sub>12</sub> analogues, and the growth of the endophyte and fixation of atmospheric N is discussed." (FA)

245. Hildenbrand, Homer.

1972. Economics and marketing of alder. In *Managing young forests in the Douglas-fir region*, Vol. 3, p. 53-61. Alan B. Berg, ed. Sch. For., Oreg. State Univ., Corvallis.

246. Hill, Fred J.

1978. Trends and technologies in southern hardwood sawmills. In *Utilization and management of alder*, p. 111-121. David G. Briggs, Dean S. DeBell, William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"This paper examines several hardwood sawmills ranging in capacity from 5 MM bd. ft. to 40 MM bd. ft. annually, and discusses the relative capital costs, operating costs, and characteristics of each facility. The paper further relates hardwood sawmill design to the characteristics of the hardwood saw-timber resource in the Eastern United States and explores the major industry concerns of (1) lack of growth in hardwood lumber production, (2) reduction in log size and quality, and (3) shifts in end-use markets. The uncertain supply of hardwood logs from small private ownership, the lack of market growth, and the variable earnings history of hardwood operations have discouraged most large corporate investment to date." (A)

247. Hillstrom, William A.

1974. Chip debarking of several western species. USDA For. Serv. Res. Note NC-164, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

"Compares procedures for removing bark from chips by compression rolls followed by 'drubbing' (tumbling and beating) the

material and then screening with or without an initial pre-steaming of the chips. Tests with four species are reported, using chips from various parts of the trees, including branches and foliage. Best bark removal was obtained with Alnus rubra (90%), followed by Tsuga heterophylla and Acer macrophyllum (60-75%); results with Pseudotsuga menziesii were slightly poorer. Pre-steaming made little difference to bark removal, but the 'drubbing' led to appreciable losses of wood fibre in P. menziesii and A. macrophyllum. After screening, and rejection of the fines, most residual bark was found in the smallest (3/16 in screen) chip material." (FA)

248. Hitchcock, C. Leo, and Arthur Cronquist.

1973. Flora of the Pacific Northwest. 730 p. Univ. Wash. Press, Seattle.

249. Hitchcock, C. Leo, Arthur Cronquist, Marion Ownbey, and J. W. Thompson.

1964. Vascular plants of the Pacific Northwest. Part 2. 597 p. Univ. Wash. Press, Seattle.

A major taxonomic reference to Pacific Northwest plants in five volumes; red alder is described in volume II. (CFH)

250. Hosie, R. C.

1973. Native trees of Canada. 380 p. Can. For. Serv., Ottawa.

Red alder is one of the species discussed in a nontechnical manner. Range map and photos included. Volume contains summer and winter keys to native Canadian trees. (CFH)

251. Hoyer, Gerald, Walter Fergerson, Michael Newton, and David R. M. Scott.  
1978. A comparison of red alder, Douglas-fir, and western hemlock productivities as related to site--a panel discussion. In Utilization and management of alder, p. 175-182. David G. Briggs, Dean S. DeBell, William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

252. Hoyer, Gerald E.

1966. Tarif access tables for the Pacific Northwest--a compilation. 118 p. Wash. State Dep. Nat. Resour., Olympia.

253. Hrutfiord, B. F.

1978. Red alder as a pulpwood species. In Utilization and management of alder, p. 135-138. David G. Briggs, Dean S. DeBell, William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"In this paper I discuss the use of alder as a pulpwood species. Today most alder pulpwood is procured as roundwood. Debarking of small and frequently crooked logs and storage are indicated as problems. Chips are rarely stored more than a month as they color rapidly and strength and yield losses occur. Use of alder in a number of pulping processes is discussed. Alder is suggested as the best prospect for whole tree chipping in the Northwest." (A)

254. Huffman, J. G., W. D. Kitts, and C. R. Krishnamurti.  
1971. Effects of alkali treatment and gamma irradiation on the chemical composition and in vitro rumen digestibility of certain species of wood. Can. J. Anim. Sci. 51(2):457-464.

"Changes in the chemical composition in vitro rumen digestibility of alder (*Alnus rubra*), Douglas-fir (*Pseudotsuga menziesii*), poplar (*Populus tremuloides*), and sludge (a by-product of the pulping process made up of silver fir and hemlock residues) were studied after treatment with NaOH and gamma irradiation. Treatment with alkali increased the percentage of cellulose and acid detergent fiber (ADF) in all species of wood studied, whereas the average acid detergent lignin (ADL) content was not affected. Alkali treatment increased the in vitro dry matter disappearance (DMD) of alder and poplar, and increased the in vitro cellulose digestion of alder, poplar and sludge. Samples of the 4 species of wood that were exposed to  $1 \times 10^8$  or  $2 \times 10^8$  rads of gamma irradiation were lower in cellulose, ADF and ADL content than the untreated samples, or those exposed to  $1 \times 10^6$  or  $1 \times 10^7$  rads. In vitro DMD, cellulose digestion and volatile fatty acid production were higher in samples of all 4 species exposed to  $1 \times 10^8$  or  $2 \times 10^8$  rads, than in untreated samples, or in those exposed to  $1 \times 10^6$  or  $1 \times 10^7$  rads." (BA)

255. Hughes, D. R., S. P. Gessel, and R. B. Walker.  
1968. Red alder deficiency symptoms and fertilizer trials. In Biology of alder, p. 225-237. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

256. Hughes, Dallas Robert.  
1967. Red alder deficiency symptoms and fertilizer trials. M.F. thesis. Univ. Wash., Seattle. 144 p.

Presents deficiency guidelines for N, P, K, Ca, and Mg developed in red alder seedlings growing in sand medium. Foliar percentages of these elements were determined as aids in diagnosing deficiencies. Nodule frequency was higher in low N treatments. Deficiency symptoms are illustrated with color photographs. Fertilizer studies were conducted with seedlings growing in soil. (CFH)

257. Hunt, Ian Sinclair.  
1957. Las propiedades y usos de la madera de *Alnus*. [Properties and uses of alder wood.] Inst. For. Lat. Am. Bol. 23, p. 29-42. Merida, Venezuela. [In Spanish. English summary.]

"Available data on the properties and uses of the wood of the commercially important species of *Alnus* are discussed and summarized.

"The commercial uses are governed by the natural occurrence of the species; apparently there have been no large scale planting of exotic species of *Alnus*, with the exception of *A. Nepalensis* in Hawaii.

"The indigenous species in commercial use are *A. rubra* in Canada and the U.S.A., *A. glutinosa* in England and Europe, *A. incana* in Western and Central Europe, *A. nepalensis* in India, and *A. jorullensis* in South America.

"A comparison is made of those physical and mechanical properties which have been reported. There are some gaps in these data, particularly for *A. jorullensis*. It is noted that the lowest test figures are shared by *A. nepalensis* and *A. jorullensis*, and the highest by *A. glutinosa* and *A. rubra*.

"The literature cited gives some indication of the extent of the knowledge of the properties and applications of the wood of *Alnus* in the various countries in which the different species occur.

"Taking into account the present use of *Alnus* wood in North America, England and Europe, the uses to which the wood of *A. jorullensis* could be put to the greatest advantage in the future in South America would be: preservative treated telephone and electricity poles, treated fence posts, treated mine props, treated wood for rural buildings, boxes and cases, patches and match boxes, turned to novelty goods, and pulp and paper." (A)

258. Hunt, K., and J. V. Hatton.  
1976. Increased pulp production by use of hardwoods in softwood kraft mills. *Pulp & Pap. Can.* 77(12):119-123.

"The kraft pulping of single softwood-single hardwood mixtures of white spruce, western hemlock, or jack pine containing up to 20% by weight of red alder, yellow birch, or trembling aspen is examined in detail. Single hardwood-single softwood mixtures cook more rapidly to a target permanganate number, and give higher pulp yields and equivalent pulp quality compared with a softwood cooks alone under the same conditions. Mixed pulps also beat faster. There are no technical limitations to the use of small amounts of hardwoods with softwoods to produce unbleached or bleached market pulps. In addition to increased pulp production, other benefits exist." (A)

259. Hyttinen, A., and E. R. Schafer.  
1955. Grinding pretreated hardwoods: Experiments on quaking aspen, sweetgum, red alder, black tupelo, sugar maple, red oak and cottonwood. *Pulp and Pap. Mag. Can.* 56(12):140-148.

"Increasing the severity of the pre-treatment with neutral  $\text{Na}_2\text{SO}_3$  increased the strength and density of the pulp but decreased the brightness and opacity of its papers. The chemi-groundwood pulp could probably be used for the same purposes as the neutral sulphite semichemical pulps. The darker pulps were easily brightened with  $\text{Ca}(\text{OCl})_2$ . These chemi-groundwood pulps may possibly provide entire or part substitutes for mechanical softwood pulps in newsprint and bood and towelling papers, and also in mixtures with mechanical hardwood pulps, a substitute for softwood groundwood. Details of the properties of the pulps, of test sheets, and of experiments in paper-making, are given for *Populus tremuloides*, *Liquidambar styraciflua*, *Alnus rubra*, *Nyssa sylvatica*, *Acer saccharum*, *Quercus* sp., and *Populus* sp." (FA)

260. Hyttinen, A., and E. R. Schafer.  
1955. Grinding pretreated  
hardwoods: Experiments on quaking  
aspen, sweetgum, red alder, black  
tupelo, sugar maple, red oak, and  
cottonwood. USDA For. Serv. For.  
Prod. Lab. Rep. 2015, 12 p.  
Madison, Wis.

"Experiments were made with Populus tremuloides, Liquidambar styraciflora, Alnus rubra, Nyssa sylvatica, Acer saccharum and Quercus sp. The effects of different pretreatment with neutral sulphite solutions are described and tabulated. The results, in addition to the easy bleaching, point to the possibility of substituting semichemical hardwood pulp in part or whole, for mechanical softwood pulp for a variety of uses." (FA)

261. Irgens-Moller, H.  
1960. Automatic control of  
photoperiod. Ecology 41(1):222-223.

"Describes methods used at Corvallis, Oregon, for the automatic control of photoperiod in greenhouse studies on Pseudotsuga taxifolia and Alnus sp. The plants are grown in separate compartments of growth chambers. These can be covered or uncovered as required by a means of a small motor, controlled by an electric time switch (wiring system shown), which moves a light-proof canvas belt, mounted on rollers, in either direction. Fluorescent lamps are fitted in the compartments and can be used either to supplement daylight or to give long-day treatment when the chambers are covered. Temperature in the greenhouse is only partially controlled, but is kept constant in all compartments even though under varying light treatments." (FA)

262. Isaac, Leo A.  
1939. Reforestation by broadcast  
seeding with small-seeded species.  
USDA For. Serv. Pac. Northwest For.  
and Range Exp. Stn. Res. Notes 27,  
p. 9-10. Portland, Oreg.

"Although there was wide variation in the results from these tests with seed of Sitka Spruce, Western Red Cedar, Western Hemlock, and Red Alder, it appears that satisfactory regeneration can be obtained by broadcast seeding at the rate of one or two pounds per acre, as long as the seeding is done within two years after slash burning. If postponed longer there is a considerable falling off in initial germination and in survival." (FA)

263. Ivan Bloch and Associates  
(Industrial Consultants, Portland,  
Oreg.).  
1964. Western markets for red alder  
from specified counties in Oregon  
and Washington: A preliminary and  
partial examination prepared for  
the U.S. Area Redevelopment  
Administration. 56 p. Portland,  
Oreg.

264. Jackson, H. S., and Elizabeth Ruth  
Dearden.  
1949. Studies of Canadian  
Thelephoraceae. III. Some new  
species from British Columbia.  
Can. J. Res., Sec. C., Bot. Sci.  
27(4):147-156.

"Descrs. of Peniophora resinosa, on  
Picea sitchensis; P. unica, on Abies lasiocarpa; P. inusitata, on Populus trichocarpa; P. phlebioides and Corticium testatum, on Pseudotsuga taxifolia; C. praeteritum, on Alnus rubra; C. separatum, on Abies grandis; C. quae situm, on Pseudotsuga taxifolia; C. propinquum, on Thuja plicata." (BA)

265. Jain, M. C., and T. R. Seshadri.  
1971. Triterpenoids from Alnus rubra. Indian J. Chem.  
9(9):1026-1027.

"Taraxerone, lupeol and betulin occur as major components and lupenone, taraxerol,  $\beta$ -sitosterol and the somewhat rare compounds taraxeryl acetate and glutenone occur as the minor components in the bark of A. rubra. Except taraxerol and taraxerone, the other six have been isolated for the first time from A. rubra. The acetone and alcohol extracts contain glucose, xylose and arabinose as free sugars and fairly good amounts of leucocyanidin." (A)

266. Jaretzky, R.  
1930. Zur Zytologie der Fagales.  
Planta 10:120-137.

267. Jenkins, J. H., and F. W. Guernsey.  
1954. The kiln-drying of British Columbia lumber. For. Prod. Lab. Can. Bull. 111, 79 p. Vancouver, B.C.

Comprehensive presentation of the general principles of kiln-drying; gives details for kiln-drying the chief commercial lumber species of British Columbia.  
(CFH)

268. Jepson, Willis Linn.  
1909. A. rubra Bong. In A flora of California, p. 347-349. Cunningham, Curtis, and Welch, San Francisco, Calif.

Describes alder and gives its range and uses in California. (CFH)

269. Jepson, Willis Linn.  
1924. A. rubra Nutt. In A flora of the economic plants of California for agricultural students, p. 70-71. Assoc. Stud. Store, Berkeley, Calif.

Describes alder and gives its range and uses in California. (CFH)

270. Johnson, Floyd A.  
1955. Volume tables for Pacific Northwest trees (a compilation). U.S. Dep. Agric. Agric. Handb. 92, 112 p.

"Gives tables (cu. ft. and bd. ft.) for Pinus ponderosa, Pseudotsuga taxifolia, Tsuga heterophylla, Picea sitchensis, Abies amabilis, Pinus contorta, Alnus rubra, Larix occidentalis, Abies concolor, A. grandis, Chamaecyparis lawsoniana, Pinus monticola, P. lambertiana, Thuja plicata, Libocedrus decurrens, Abies procera, Picea engelmannii and Populus trichocarpa."  
(FA)

271. Johnson, Floyd A., R. M. Kallander, and Paul G. Lauterbach.  
1949. Volume tables for red alder. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Notes 55, 10 p. Portland, Oreg.

"The tables are based on figures from Oregon, Washington, and British Columbia." (FA)

272. Johnson, Floyd A., and Norman P. Worthington.  
1963. Procedure for developing a site index estimating system from stem analysis data. USDA For. Serv. Res. Pap. PNW-7, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The procedure presented in this report has been applied successfully to three tree species. It is simple, direct, and apparently statistically sound. Perhaps others, faced with the problem of developing site curves from stem data, will find it useful." (FA)

273. Johnson, Frederic D.  
1968. Disjunct populations of red alder in Idaho. In Biology of alder, p. 1-8. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Alnus rubra Bong., red alder, has been collected in several areas in northern Idaho. This is the eastern limit of the species and appears to be a definite disjunct of the Pacific coastal distribution. Development is centered in three main areas and is shown on range maps around Lake Pend Oreille, Bonner Co., lower Selway-Lochsa Rivers, Idaho Co., and North Fork Clearwater River, Clearwater Co. All of these areas are in the western redcedar-western hemlock vegetational zone; observations on ecological associations are made. Probable hybridization with other alders is reported." (A)

274. Johnson, Frederic D.  
1968. Taxonomy and distribution of northwestern alders. In Biology of alder, p. 9-22. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Synonymy, morphological features, and distribution of the four northwestern North American species of Alnus - A. rhombifolia, A. rubra, A. tenuifolia, and A. sinuata - are outlined. Included are distribution maps, a synoptic view of vegetative characteristics, and photos of buds and leaves." (A)

275. Johnson, Herman M.  
1917. Alnus oregonia: Its value as a forest type on the Siuslaw National Forest. J. For. 15(8)981-987.

"Although the Oregon alder has been commonly considered a weed tree and in many respects undesirable, this study has shown that it has been and is yet of great value to the Siuslaw National Forest. Its function as a nurse crop to the more valuable Douglas-fir is making possible the restoration of the valuable timber which once covered this region. It is revivifying the depleted soil, making possible the prosperous communities scattered along the coast. Its presence has made impossible the extensive fires which formerly devastated this region. Lastly, its value as a commercial product is being realized, and it may be expected that in the near future it will develop an industry of considerable extent." (A)

276. Johnson, Herman M., Edward J. Hanzlik, and William H. Gibbons. 1926. Red alder of the Pacific Northwest. Its utilization, with notes on growth and management. U.S. Dep. Agric. Dep. Bull. 1437, 46 p. Washington, D.C.

"Alnus oregona is the most abundant and commercially the most important hardwood in Oregon and Washington. It is found along the Pacific Coast from southern California to southeastern Alaska, rarely more than 40-50 miles inland. It occurs at the lower altitudes in pure stands in rather small units, also in mixed stands with Douglas fir, western hemlock, western red cedar, and Sitka spruce. Other hardwoods associating with alder are bigleaf maple, black cottonwood, Oregon ash, cascara, and Pacific dogwood. The merchantable stand is estimated at 750 million board ft. in Oregon and 360 million in Washington. The wood is moderately light, even-grained and soft in texture, and compared with oak is moderately weak. It weighs 46 lbs. per cu. ft. when green and 27 lbs. when kiln-dried to 8% moisture. It is not naturally durable but presents no special difficulties in seasoning. About 13-1/2 million board feet was cut in 1923, or only 0.2% of the total cut of hardwood lumber in the U.S.A. Of this, 12 million ft. was used in the manufacture of furniture. Other products were wooden ware and novelties, veneer fixtures, brush and broom handles, and general mill work. Experiments have indicated that it is suitable for pulping by the soda process. Considerable quantities of round wood are used in making charcoal for gun powder. Red alder grows fairly rapidly for 50-60 yrs. Trees at 50 yrs. of age average 16.0 in. in diam., 97.5 ft. tall, and contain 52 cu. ft. (335 board ft.). In 50 yrs., pure alder

stands can be expected to yield 15-40 M board ft. to the acre. The bulletin contains volume tables for alder (in board ft. and cu. ft.) and concludes with a classified list of present and possible uses of the wood; and a directory of producers of alder logs, lumber, and other alder products in Oregon and Washington." (BA)

277. Johnson, R. L. 1978. Hardwood culture in the Eastern United States. In Utilization and management of alder, p. 55-59. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Many hardwood plantations are being established in the East. Populus deltoides, Platanus occidentalis, Liquidambar styraciflua, and Juglans nigra are the species that have been planted and studied most." (A)

278. Johnsson, Helge. 1951. Lovtrad in Svensk Vaxtforadling. Natur och Kultur, P. 795-799. [In Swedish.]

279. Johnsson, Helge, and Aake Ljunger. 1959. Betula, Alnus, Fagus, Quercus, Fraxinus, Castanea, Juglans. Handb. der Pflanzenzuecht. Vol. 6. 2d ed. p. 806-818. [In German]

280. Jones, George Neville.  
1936. A botanical survey of the  
Olympic Peninsula, Washington.  
Univ. Wash. Publ. Biol., Vol. 5,  
286 p. Seattle, Wash.

A discussion of the botanical features of the Olympic Peninsula based on 10 years of field experience and a compilation of literature through 1935. The zonal distribution and geographical relationships of the vegetation and history of botanical exploration are discussed. Keys to families and species are included. Red alder is a component of the Douglas-fir subclimax within the transition zone. (CFH)

281. Jones, J. R. I. L.  
1943. Some food plants of  
Lepidopterous larvae. List 9.  
Entomol. Soc. B.C. Proc. 40:27.

"The list includes Acronicta (Apatela) funeralis on Willow (Salix scouleriana and some ornamental species) and Carolina Poplar; A. illita on Quercus robur and Alnus rubra; A. distans dolorosa on Alnus rubra; Halisidota maculata angulifera on Salix hookeriana and S. scouleriana; Hyphantria textor on Salix lasiandra; Malacosoma disstria erosa on Alnus rubra; M. pluvialis on Prunus emarginata; Nadata gibbosa oregonensis on Castanea sp.; Phoesia portlandia on Salix lasiandra, S. hookeriana, S. scouleriana, Populus trichocarpa and P. tremuloides, Pseudothyatira cymatophoroidea on Crataegus oxyacantha, Scoliopteryx libatrix on Salix lasiandra, S. scouleriana, Populus trichocarpa and Lombardy Poplar, and Schizura unicornis on Crataegus oxyacantha." (FA)

282. Karchesy, Joseph J., Murray L. Laver, Douglas F. Barofsky, and Elisabeth Barofsky.  
1974. Structure of oregonin, a natural diarylheptanoid xyloside. J. Chem. Soc. Chem. Commun. 1974(16):649-650.

"The structure of oregonin,  $3-(HO)_2C_6H_3(CH_2)_2COCH_2CH(OR)(CH_2)_2C_6H_3(OH)_2$ -3,4 (R-xylosyl), a diarylheptanoid xyloside extd. from Alnus rubra, was detd. from chem. and spectral data." (BA)

283. Karchesy, Joseph J., Patricia M. Loveland, Murray L. Laver, Douglas F. Barofsky, and Elisabeth Barofsky.  
1976. Condensed tannins from the barks of Alnus rubra and Pseudotsuga menziesii. Phytochemistry 15(12):2009-2010.

Describes isolation and identification of condensed tannins from red alder and Douglas-fir barks. (CFH)

284. Karchesy, Joseph John.  
1975. Polyphenols of red alder: Chemistry of the staining phenomenon. Ph. D. thesis. Oreg. State Univ., Corvallis. 112 p.

"A cold-acetone extract of bark from Alnus rubra yielded a condensed tannin fraction that did not contribute to the staining phenomenon, and a diarylheptanoid xyloside, to which the name oregonin is given. Oregonin was implicated in the staining phenomenon through its ability to form orange-red colours. Spectral data and physical constants are given for the condensed tannin fraction, for oregonin and for seven derivatives and related synthetic products.

285. Keller, E. L., J. S. Martin, and R. M. Kingsbury.

1956. Semichemical pulping characteristics of Pacific coast red alder, Douglas-fir, western redcedar, and western hemlock. USDA For. Serv. For. Prod. Lab. Rep. 1912, 25 p. Madison, Wis.

286. Kellman, M. C.

1970. The viable seed content of some forest soil in coastal British Columbia. Can. J. Bot. 48(7):1383-1385.

"The upper 10 cm of surface soil and litter beneath a coniferous forest in coastal British Columbia was found to contain over 1000 viable seeds per square meter. Alnus rubra Bong. made up 68.9% of all viable seed, although 18 other species, mainly weedy and secondary types, were recorded." (A)

"This paper brings together information regarding regeneration of red alder (Alnus rubra Bong.) from published and unpublished sources. Based on this evidence, red alder does not appear to be a difficult species to regenerate, either naturally or artificially. This should come as no surprise to Pacific Northwest foresters. Red alder reaches sexual maturity at around age 10 and produces large quantities of seed annually, with bumper crops about every 4 years. Natural regeneration occurs in open, disturbed areas where mineral soil is exposed. Seedlings may reach 3 feet in height the first year, and grow to 15 feet in 5 years. Alder seedlings have been successfully grown in both bare root and container nursery systems. Stratification of seed does not appear to be essential for reasonable levels of germination. Plantations of red alder have done well where reported. Coppicing of young alder is possible and offers an alternative fiber production system." (A)

287. Kellman, M. C.

1972. Erratum: The viable seed content of some forest soil in coastal British Columbia. Can. J. Bot. 50(7):1639.

"A corrective note, reidentifying as Betula papyrifera var. commutata the species previously identified as Alnus rubra." (FA)

289. Kennedy, R. W., and G. K. Elliot.  
1957. Spiral grain in red alder.  
For. Chron. 33(3):238-251.

"The occurrence and severity of spiral grain in Alnus rubra was investigated on two sites, one poor and one medium-good. The changing spiral was measured at breast height and at 10-ft. intervals above ground level. No straight-grained tree was found on either site, and it is concluded that the feature is genetically controlled, though the amount of spirality is affected by growth rate. Individual trees vary greatly, but the general spiral pattern is the same--an initial right spiral, followed by an increasing left spiral. The possibility of controlling growth rate so as to have as little spiral as possible in the outer wood of the tree, is discussed." (FA)

288. Kenady, Reid M.

1978. Regeneration of red alder. In Utilization and management of alder, p. 183-191. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

290. Kennedy, R. W., and G. Ifju.  
1962. Applications of microtensile testing to thin wood sections.  
*Tappi* 45(9):725-733.

"Describes three applications of microtensile testing: (1) a wood-quality evaluation of Douglas Fir; (2) a test of the effect of incipient decay, using 4 woods and 4 fungi; (3) a comparison of wood decay and dilute-acid hydrolysis. The strength differences noted in (1) were correlated with other chemical, physical, and anatomical properties of the wood. The 16 fungus/wood species combinations tested in (2) were ranked in order of progressively greater strength loss per unit weight loss into: (i) all species (Alnus rubra, Betula papyrifera, Tsuga heterophylla, and Abies sp.) decayed by Polystictus versicolor (a); (ii) all species decayed by Stereum sanguinolentum (b) and the conifers of Poria monticola (c) and Lentinus lepideus (d); (iii) the hardwoods by (c) and (d). Contents of holo- and  $\alpha$ -cellulose determined for the decayed woods indicated a far greater reduction in degree of polymerization in woods rotted by (c) and (d) than in woods decayed to comparable weight losses by (a) and (b). The residual tenacity and holo-cellulose content of acid-treated woods were similar to those decayed by (a) to equivalent weight losses. The mechanical and chemical effects of (c) and (d), particularly on the hardwoods, were distinct from those of weak acid hydrolysis, which proceeded in a more heterogeneous fashion through selective removal of the hemicelluloses, and consequent retention of the more resistant  $\alpha$ -cellulose." (FA)

291. King, A. D., Jr., W. L. Stanley, L. Jurd, and F. P. Boyle.  
1971. Wood chip microbiological control with sulfur dioxide. *Tappi* 54(2):262.

"Small scale experiments with Alder chips treated with  $\text{SO}_2$  gas to give uptakes of 0.1, 0.5 and 1% by weight and stored for 3 months at 22° C. indicate that chips can be effectively sterilized by treatment with 0.5 or 1%  $\text{SO}_2$ . The ability of  $\text{SO}_2$  to sterilize as well as to bleach suggests that the possibility of using it economically in chip storage should be studied more intensively." (FA)

292. King, David G., Al Grass, and Ken Summers.  
1973. Observations on the dipper in the Skagit Valley of British Columbia. *Murrelet* 54(2):16-19.

Discusses the distribution and number of the dipper (Cinclus mexicana) in the lower Skagit Valley in southern British Columbia in winter 1970. Red Alder is a major component of the streamside banks. (CFH)

293. Kirsch, R. K.  
1959. Effect of saw dust mulches. I. Soil properties. Oreg. Agric. Exp. Stn. Tech. Bull. 49, 16 p.

"When Douglas Fir sawdust was applied with or without fertilizers as a mulch or soil amendment, strawberries became infested with red-stele disease. Soil samples were taken after rotovating all plots, and sweet corn was planted to determine residual effects. The results of analyses are presented. A further study of the effect of Douglas Fir and Alder sawdust on certain physical soil properties is summarized." (FA)

294. Kitts, W. D., C. K. Krishnamurti, J. A. Shelford, and J. G. Huffman. 1969. Use of wood and woody by-products as a source of energy in beef cattle rations. *Adv. Chem.* Ser. 95:279-297.

"The incorporation of sawdust in beef cattle rations has been investigated using three approaches. *In vivo* feeding trials with growing beef cattle indicate that there was no appreciable differences in the daily weight gain of steer when alder sawdust was substituted for hay in their rations. When hemlock sawdust, subjected to gamma radiation up to a maximum of  $1.46 \times 10^8$  radiation, was used as a substrate for *in vitro* rumen fermentation, percentage dry matter disappearance and cellulose digestion showed a steady increase with increasing irradiation levels. The amount of reducing sugars formed from irradiated sawdust by incubation with cell-free extracts of rumen micro-organisms followed the same patterns as the *in vitro* fermentation tests." (A)

295. Kliewer, Mark, and Harold J. Evans. 1962.  $B_{12}$  coenzyme content of the nodules from legumes, alder, and *Rhizobium meliloti*. *Nature* (London) 194(4823):108-109.

Describes procedure and gives results of extractions of  $B_{12}$  coenzymes from root nodules. (CFH)

296. Kliewer, Mark, and Harold J. Evans. 1962. Physiological studies on the  $B_{12}$  coenzyme content of nodules from legumes and alder of *Rhizobium* species. (Abstr.) In *Proceedings of the plant physiology meetings*, 1962. *Plant Physiol.* 37(Suppl.):6-7.

297. Kliewer, Mark, and Harold J. Evans. 1963. Cobamide coenzyme contents of soybean nodules and nitrogen-fixing bacteria in relation to physiological conditions. *Plant Physiol.* 38:99-104.

"Nodules showed a gradual increase in the content of the vitamin  $B_{12}$  coenzyme (I) with age up to flowering, and then a decline. The increase in I was paralleled by an increase in hemoglobin. There was a wide range in I concn. in 5 species of *Rhizobium*, but only small differences between effective strains of the same species. Ineffective and parasitic strains of *R. meliloti* and *R. japonicum* contained less I than the effective strains. I in these species was markedly increased with increasing Co in the medium, and one was present when Co was lacking. *Azotobacter vinelandii* required only 0.001 p.p.b. for normal growth, and more Co was required when  $N_2$  was the source of N than when  $NH_3$  was the source." (CA)

298. Kliewer, Mark, and Harold J. Evans. 1963. Identification of cobamide coenzyme in nodules of symbionts and isolation of the vitamin  $B_{12}$  coenzyme from *Rhizobium meliloti*. *Plant Physiol.* 38:55-59.

"Appreciable amts. of cobamide coenzyme (I) were found in the nodules of legumes (alfalfa, soybean, pea, bean, and red clover) and also in those of the non-legumes *Alnus rubra* and *Ceanothus velutinus*. *R. meliloti* was grown on a large scale and I was isolated in a highly purified form. From spectral properties chromatographic behavior, and biol. activity it was concluded that I was (5,6-dimethylbenzimidazolyl) combamide." (CA)

299. Knutsen, Stanley Kenneth.  
1965. Hydrologic processes in thirty- to thirty-five-year-old stands of Douglas-fir and alder in western Washington. M. F. thesis. Coll. For. Resour., Univ. Wash., Seattle. 167 p.

Interception of rainfall for the period January 1 to August 31, 1964, was 10 percent for alder and 15 percent for Douglas-fir. Interception was seasonal; 9 percent in January-March and 13 percent in July and August for red alder. Corresponding values for Douglas-fir are 14 and 21 percent. Stemflow was less in summer than winter, amounting to 2.7 percent of rainfall in alder and 7 percent in Douglas-fir. Other hydrologic measurements are available. (CFH)

300. Kohnke, Helmut.  
1941. The black alder as a pioneer tree on sand dunes and eroded land. J. For. 39(3):333-334.

301. Kozak, A., and J. H. G. Smith.  
1966. Critical analysis of multivariate techniques for estimating tree taper suggests that simpler methods are best. For. Chron. 42(43):458-463.

"Trials of multivariate and other methods for analysis of tree taper are described. It is concluded that use of simple functions, sorting and graphical methods is adequate for many uses in operations and research." (A)

302. Kozlik, C. J.  
1967. Establishing color in red alder lumber. Oreg. For. Prod. Lab. Rep. D-8, 11 p. Corvallis, Oreg.

"Steaming Alnus rubra lumber at 212° F and 100% r.h., for  $\frac{1}{2}$  hr. before air- or kiln-drying, eliminated sticker stain, prevented mottling, and produced a uniform colour ranging from white (sapwood) to ivory (heartwood). Steaming air-dried lumber at 212° F and 100% r.h. for 4-24 hr. eliminated previous sticker stain and gave a uniform, colour with insufficient mottling to cause degrade, but the boards lacked lustre. Forced-air drying of lower grades of lumber was uneconomic in the prevailing weather conditions; drying cost was \$5.06/1000 bd. ft., and additional kiln drying was required." (FA)

303. Kozlik, Charles J.  
1962. Seasoning red alder lumber. Oreg. For. Prod. Lab. Rep. D-6, 20 p. Corvallis, Oreg.

"Tests were made on red alder lumber to study the effects on drying time and degrade of various dry-bulb temperatures, equilibrium moisture content (e.m.c.) conditions, air velocities, and periods of fan-reversal, pre-streaming, and conditioning. Treatments were judged favourable if they led to reduction of drying time without excessive increase in degrade. A schedule is detailed for drying 1-in. lumber in ca. 85 hr.; 1-1/4-in. lumber can be dried under the same conditions (though more time is needed), but 1-1/2-in. lumber should be dried by less severe conditions to avoid excessive degrade." (FA)

304. Kozlik, Charles J.  
1978. Stabilizing color and drying red alder. In Utilization and management of alder, p. 93-101. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"A honey-brown color is established without difficulty in drying freshly sawed red alder lumber, but a reddish-tan to reddish-brown color required dry-bulb temperatures about 185° F at 92-percent relative humidity or higher. A white or ivory color is obtained by steaming freshly saw or partially air-dried lumber at 212° F and 100-percent relative humidity. The white color may be retained with air drying, but a honey-brown to reddish-brown color requires kiln krying immediately after setting the color. Kiln-drying practices depend on kiln capacity, boiler capacity, availability of logs, log storage, and customer specifications. Initial dry-bulb temperatures range from 150° to 190° F, and drying times for 4/4 lumber vary from 4 to 6 days. Equalizing for uniformity of final moisture content and conditioning to remove drying stresses for remanufacturing are important steps in drying for both producer and customer." (A)

305. Krueger, Kenneth W., and Robert H. Ruth.  
1968. Photosynthesis of red alder, Douglas-fir, Sitka spruce, and western hemlock seedlings. (Abstr.) In Biology of alder, p. 239. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"More rapid growth by red alder seedlings than by associated coastal conifers creates interest in their comparative photosynthetic behavior. Seedlings of the four species, previously grown under light and heavy shade, were brought to the laboratory at intervals during their second growing season for measurement of photosynthetic rate by infrared CO<sub>2</sub> analysis at five light intensities.

"Photosynthetic rates expressed on a leaf-area basis did not differ greatly between species up to saturating light intensities for the conifers. The conifers, especially western hemlock, reached maximum rates at lower light intensities than did alder. Growing the four species under heavy shade tended to decrease species differences in photosynthetic rates.

"The distribution of plant weight between photosynthetic and nonphotosynthetic tissue was generally similar for all species. Alder produced more leaf area per unit weight of leaf, however. In the dark, respiration rate per gram of top was highest for alder.

"Greater capacity to utilize high light intensities for photosynthesis combined with more area per unit weight of leaf and greater total leaf area per seedling may contribute substantially to alder's faster growth in high light situations. (A)

306. Krueger, Kenneth W., and Robert H. Ruth.  
1969. Comparative photosynthesis of red alder, Douglas-fir, Sitka spruce, and western hemlock seedlings. *Can J. Bot.* 47(4):519-527.

"More rapid growth by red alder than by coastal conifer species may be explained by alder's greater foliage surface per unit foliage weight, greater total foliage area per seedling, and higher photosynthetic rate at high light intensities. Net photosynthetic rates per unit foliage areas were similar for red alder and the three conifers up to saturating light intensity for the conifers. Relative weight of photosynthetic and nonphotosynthetic tissue was also similar for the four species. Average maximum photosynthetic rates measured for these conifers are comparable to reported rates for woody broad-leaved species." (A)

307. Kuntze, Otto.  
1891. *Revisio generum plantarum.* Wurzburg. p. 638-640.

308. Kurth, E. F.  
1950. The chemical analysis of western woods. Part III. *Tappi* 33(10):507-508.

"Four species of western hardwoods (Acer macrophyllum, Alnus rubra, Lithocarpus densiflorus, and Castanopsis chrysophylla) and 4 species of western softwoods (Pinus contorta var. latifolia, Chamaecyparis nootkatensis, Abies grandis, and Abies procera) have been analysed for ether, alcohol and water extractives, holocellulose, lignin, methoxyl group, acetyl group, and ash content." (FA)

309. Kurth, E. F., and Edwin L. Becker.  
1953. The chemical nature of the extractives from red alder. *Tappi* 36(10):461-466.

"The bark of Alnus rubra has been found to contain 24.0% of extractives, its wood 8.6%. The main white colouring matters in the bark are alnulin and protalnulin; the red colouring matters are a phenolic xyloside, phlobatannin, a tannin-carbohydrate complex, and phlobaphene. The tannin contents are 4.2% in the bark and 0.74% in the wood." (FA)

310. Lai, Yuan-Zong.  
1966. A study of the peracetic acid oxidation of Douglas-fir and red alder woodmeal. M.S.F. thesis. Univ. Wash., Seattle. 58 p.

Peracetic acid oxidation of Douglas-fir and red alder woodmeal results in the formation of a water-soluble lignin product. Yields are approximately 20 percent of the dry wood material. Red alder woodmeal is more easily attacked by peracetic acid. The analytical composition of Douglas-fir peracetic acid lignin is similar to that of red alder lignin.

An electrophilic aromatic substitution can explain the oxidation of lignin by peracetic acid. Guaiacyl and syringyl units, with a free phenolic hydroxyl group, are converted to muconic acid structure. The etherified units proceed to the formation of 1:4-benzoquinone, and by further oxidation of this to the fumaric acid derivative. Peracetic acid lignin still contains some undegraded aromatic rings.

Yields of periodate lignin for Douglas-fir and red alder preparation were approximately 22 percent on the basis of dry wood material, and about 88 percent of the lignin initially present

in wood. Red alder periodote lignin is more easily attacked by peracetic acid than that of Douglas-fir lignin. (CFH)

311. L'Allemand, Gordon.

1965. Red alder is a preferred species. Woodworking Dig. 67(4):34-38.

"Briefly discusses the physical, mechanical and working properties of *Alnus rubra* and compares it with other hardwoods as a furniture timber." (FA)

312. Lanner, Ronald M.

1964. Adventitious rooting - a response to Hawaii's environment. USDA For. Serv. Res. Note PSW-54, 3 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

"In the very humid climate of Hawaii, adventitious roots have been noted on the stems or branches of the following exotics, which in their own habitats rarely, if ever, form them: Eucalyptus robusta, Melaleuca leucadendron, Cryptomeria japonica, Alnus nepalensis, A. rubra, Fraxinus uhdei, Casuarina cunninghamiana, and C. littoralis." (FA)

313. Lanner, Ronald M.

1964. Clones of Nepal alder in Hawaii. J. For. 62(9):636-637.

"Observations in a 26-year plantation of Alnus nepalensis which suffered heavy losses from wind revealed that epicormic shoots had grown vertically from wind-thrown trees and put out adventitious roots, giving rise to clonal groups." (FA)

314. Larsen, Lee E.

1967. Current work on the new Soderhamn chippers. Tappi 50(2):61A-64A.

"The method of chip preparation has a great effect on the quality of the pulp produced. Recent developments in chipper design tend to minimize chip damage and contribute to improved sulfite pulp strength. Laboratory results obtained on chips produced from two new chippers, the Soderhamn Drum chipper and the H-P chipper, are compared with the results of chips produced by the conventional disk chipper." (A)

315. Larson, Don.

1976. Nitrogen-fixing shrubs: An answer to the world's firewood shortage? Futurist 10(2):74-77.

"The growing scarcity of firewood in the world's under-developed countries could be eliminated in five to 15 years if nitrogen-fixing shrubs were planted in wastelands that cannot now support trees or crops. These plants have their own built-in supply of nitrogen and can survive in sterile, barren lands where nearly all other plants perish. In addition, such super-hardy plants would check wind and water erosion, reduce runoff, and replenish the fertility of long-impooverished soils." (A)

316. Larson, William H.  
1951. Forest roadside control of alder and willow. J. For. 49(10):705-707.

"A standard tank truck with Griswold 1-in. fog nozzle and 6-ft. applicator was used for spraying roadside brush in Douglas Fir forest, consisting mainly of Willow and Red Alder. Of the various concentrations of Na salt of 2,4-D tried, it was found that the 500 p.p.m. solution was satisfactory. For a 500-gal. charge of this solution, 2-1/2 lb. of 'Special Mix' and 1-1/4 lb. of 82% 2,4-D (costing \$4.00 together) were used. Best results were obtained between mid-May and June. Total costs vary with local conditions, accessibility and water etc., but it is estimated that in the experiment the cost was \$11.90 per mile sprayed, exclusive of travel to and from the job, broken hose etc. Observations of treated strips 2 years after treatment showed that they were still substantially free from regrowth." (FA)

317. Laundrie, J. F.  
1959. Continuous cold soda pulping of west coast red alder, tanoak, madrone, and bigleaf maple. USDA For. Serv. For. Prod. Lab. Rep. 2162, 12 p. Madison, Wis.

318. Lawton, Donald M.  
1972. Alder challenges established hardwoods. Woodworking & Furniture Dig. 74(2):28-30.

Red alder is gaining an ever-increasing share of U.S. and Canadian furniture manufacturing markets. Alder production in Oregon and Washington in 1970 was over 250 million board feet, an increase of 25 percent since 1960. Includes a brief

description of red alder properties and case histories of use by various manufacturers throughout the United States. (CFH)

319. Leech, H. E.  
1942. Hemichroa crocea Fourcroy. Entomol. Soc. B.C. Proc. 39:35.

"Larvae of this sawfly were taken on Alnus sp. at Gleneden, near Salmon Arm, June 1941. In Br. Columbia it was previously known only from the lower Fraser Valley." (BA)

320. Leney, L., A. Jackson, and H. D. Erickson.  
1978. Properties of red alder (Alnus rubra Bong.) and its comparison to other hardwoods. In Utilization and management of alder, p. 25-33. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Red alder is compared with several common commercial hardwoods of the United States. The objective is to show that alder is suitable for many products for which other hardwoods of similar structure and specific gravity are used. One advantage of alder is its uniform color of both heartwood and sapwood. A limited test of alder specific gravity showed a range of 0.33 to 0.48 and no correlation with growth rate. Tension wood is shown not to be a problem in alder and not easy to detect. Growth stresses are believed to be more of a problem, causing the splitting of logs and warpage of lumber." (A)

321. Leonard, O. A., Summarizer.  
1961. Undesirable woody plants.  
Res. Progr. Rep. West. Weed Control  
Conf. 1961:16-26.

"Alnus rubra--A 1/1 mixture of 2,4,5-T ÷ 2,4-D in diesel oil, applied basally during the growing season, gave effective and economic defoliation of stems of 2.5 in. d.b.h., but dormant-season applications have satisfactory defoliation only of trees < 1 in. in d.b.h. and were more effective on dry than on wet tree stems." (FA)

322. Lettman, Gary James.  
1977. The role of red alder in forest management in Washington.  
M.S. thesis. Wash. State. Univ., Pullman. 36 p.

"An analytical model was developed to help the owner of forest land in Washington determine if it would benefit him to consider red alder as part of his management regime. Relevant economic and environmental considerations were examined in a survey of the literature. During the course of the study personnel associated with the Northwest Hardwood Association, and spokesmen for several private industrial timberland owners and manufacturers of hardwood lumber were interviewed.

"Alder was found to be a potentially valuable tool in forest management in Washington. Evaluation of economic trends and recent advances in knowledge of the biology of alder indicated that alder could be used in many situations to increase forest productivity and to help produce a maximum sum of values from our forest land resource." (A)

323. Lewis, Meriwether, and William Clark.  
1905. Original journals of the Lewis and Clark Expedition 1804-1806, in 7 volumes and an atlas. Ruben Gold Thwaites, ed. Dodd Mead and Co, New York.

On October 30, 1805, near the Big Rapid of the Columbia River (The Dalles), Clark, describing vegetation, writes "...and a timber resembling the beach in bark but different in the leaf which is Smaller and the tree Smaller." The editor identifies it as red alder. Later both men describe it in detail in their journal entry of February 9, 1906, calling it black alder; they mention it occasionally thereafter. (CFH)

324. Li, C. Y.  
1974. Phenolic compounds in under-story species of alder, conifer, and mixed alder-conifer stands of coastal Oregon. *Lloydia* 37(4):603-607.

"Phenolic compounds in hydrolysates and neutral extracts of leaves of understory vegetation in stands of red alder (Alnus rubra Bong.), conifer, and mixed alder-conifers near coastal Oregon were determined by two dimensional thin-layer chromatography coupled with different spraying reagents. p-Coumaric, p-hydroxybenzoic, and vanillic acids occurred in all species except Galium triflorum, which lacked p-hydroxybenzoic acid. Ferulic acid occurred in about two-thirds of the species. Proto-catechuic and caffeic acids occurred sporadically among the species. Gentisic and syringic acids occurred in Stachys mexicana, Menziesia ferruginea, and Ceanothus velutinus. Acer circinatum contained syringic acid. C. velutinus leaves also contained phloroglucinol. Root nodules of alder and roots of

Ceanothus were additionally extracted. The belowground parts of these species more resembled each other in content of phenolic compounds than they resembled leaves of their own respective species." (A)

325. Li, C. Y., K. C. Lu, E. E. Nelson, W. B. Bollen, and J. M. Trappe. 1969. Effect of phenolic and other compounds on growth of Poria weiri in vitro. *Microbios*, Cambridge 3:305-311.

"Growth of the two isolates tested was strongly inhibited in media containing coumarin, 4-hydroxycoumarin or 7-hydroxycoumarin at concentrations of 0.5 and 2.0 mM and by o-catechol, salicylic acid, benzoic acid, ferulic acid, o-coumaric acid, and phenylacetic acid at 2.0 mM. Other compounds, including three known to occur in Alnus rubra or other Alders, viz. caffeic, chlorogenic and gentisic acids, inhibited only one of the isolates; still others, including some also found in Alders, had no effect or stimulated growth. Ferulic acid was the only compound reported from Pseudotsuga menziesii and Tsuga heterophylla that inhibited P. weiri in vitro. The possible role of such compounds as factors in the resistance of trees to P. weiri is discussed." (FA)

326. Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen. 1967. Selective nitrogen assimilation by Poria weiri. *Nature* 213(5078):814.

"Experiments were designed to determine (a) the relative growth of P. weiri when supplied with N equivalents in

nitrate, ammonium, or amino forms, and (b) whether P. weiri produces nitrate reductase. It was found that this fungus did not use nitrate as an N source but grew well with ammonium or amino N. Its behaviour in culture was markedly similar to that reported for Armillaria mellea, another serious destroyer of tree roots. Moreover, cell-free extracts of P. weiri completely lacked nitrate reductase activity. These findings are discussed in relation to the fact that soil under stands of Alnus rubra in mixture with conifers has been found to be markedly higher in nitrate N than soil under an adjacent stands of pure conifers. It is suggested, tentatively, that A. rubra mixed with conifers has a potential value for the biological control of P. weiri and probably other pathogens on many sites of the Douglas Fir region." (FA)

327. Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen. 1968. Enzyme nitrate reductase of some parasitic fungi. USDA For. Serv. Res. Note PNW-79, 4 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Eight parasitic fungi, Fusarium avenaceum, F. oxysporum, Gliocladium roseum, Phytophtora cinnamomi, Pythium debaryanum, Poria weiri, Trichothecium roseum, and Verticillium alboatrum, were grown in liquid culture to determine the ability of each to produce nitrate reductase, an enzyme necessary to convert nitrate nitrogen into the more easily used ammonium form." (A)

328. Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen.  
1968. Enzyme systems of red alder and Douglas-fir in relation to infection by Poria weiri. In Biology of alder, p. 241-250.  
J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds.  
Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Poria weiri hyphae secreted compounds, presumably phenoloxidases, that resulted in oxidation of catechol, DL-dopa, and hydroquinone but not P-cresol. Phenoloxidases with similar activity were found in red alder leaves but were lacking in Douglas-fir leaves. Leaves of both alder and Douglas-fir showed peroxidase activity, but at much higher levels in alder than in fir. Alder leaves were able to reduce nitrate nitrogen, presumably through presence of nitrate reductase, whereas leaves of Douglas-fir lacked apparent nitrate-reducing ability.

"These preliminary studies will be followed by studies on wood and roots of alder and Douglas-fir. If, as is likely, the phenols and phenoloxidase system in red alder leaves are also present in roots, a reason for alder's resistance to Poria weiri can be hypothesized. On penetration by the fungus, the o-dihydric phenols in alder tissue would be oxidized into fungitoxic compounds through the catalytic action of the phenoloxidases. These compounds, deposited about the periphery of the initial infection, would inhibit further spread of the fungus. Peroxidase activity, too, might contribute to resistance. Nitrate reductase activity assumes possible importance in that Poria weiri cannot reduce nitrate, whereas many of its antagonists can. Thus, the high nitrate levels in stands containing alder are not directly usable by P. weiri but permit buildup of high populations of antagonists." (A)

329. Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen.  
1970. Inhibition of Poria weiri and Fomes annosus by linoleic acid. For. Sci. 16(3):329-330.

"The K salt of linoleic acid inhibited growth in cultures of P. weiri linearly up to a concentration of 1.0 mg./ml. of acid in the medium. Growth became negligible when the concentration was increased from 0.75 to  $\geq$  1.0 mg./ml. F. annosus grew moderately well at all concentrations tested, but inhibition increased with increase of the linoleic acid concentration. Results suggest that the linoleic acid produced by Alnus rubra is an important factor in its resistance to infection by P. weiri and may reduce the longevity of the fungus in soil beneath the trees. A similarly strong inhibition of F. annosus in nature seems less likely on the basis of present data." (FA)

330. Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen.  
1970. Separation of phenolic compounds in alkali hydrolysates of a forest soil by thin-layer chromatography. Can. J. Soil Sci. 50(3):458-460.

"Describes the extraction and separation by thin-layer chromatography of phenolic compounds in a soil extract from beneath a tree of Alnus rubra at Cascade Head Experimental Forest, Oregon." (FA)

331. Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen.  
1972. Nitrate-reducing capacity of roots and nodules of Alnus rubra and roots of Pseudotsuga menziesii. Plant and Soil 37(2):409-414.

"Nitrate was reduced by root segments of A. rubra and (more than twice as quickly) by root nodules. Root segments of P. menziesii failed to reduce nitrate in spite of treatments designed to induce such activity. The reported favourable response by P. menziesii to nitrate fertilizer may be ascribed either to microbial assimilation to nitrate ions with subsequent liberation of ammonium in the soil, or to nitrate assimilation by fungi that form mycorrhizae with Douglas Fir roots." (FA)

332. Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen.  
1972. Poria weiri-inhibiting and other phenolic compounds in roots of red alder and Douglas-fir.  
Microbios 5(17):65-68.

"A thin-layer chromatographic study revealed the presence of phenolic compounds in bound forms only. Acid hydrolysates yielded vanillic acid from both species (ca. twice as much in the susceptible Douglas Fir as in the resistant Red Alder), and syringic acid from Alder only. Alkaline Hydrolysates yielded syringic, ferulic and p-coumaric acids in Red Alder, and vanillic, p-hydroxybenzoic and p-coumaric acids in Douglas Fir. Of these, ferulic, syringic, and vanillic acids have been shown to inhibit growth of the pathogen in vitro. Further research is needed to elucidate resistance mechanisms." (FA)

333. Li, Ching-Yan.  
1969. Biological influence of red alder on Poria weiri and other root rot pathogens. Ph. D. thesis. Oreg. State Univ., Corvallis. 104 p.

"Subjects covered include: the ability of P. weiri to use different N sources; the populations of bacteria, fungi and Streptomyces antagonistic to P. weiri in soils under Red Alder and Alder/conifer stands; temperature and pH requirements of P. weiri; the oxidative enzymes of P. weiri and leaves and roots of Red Alder and Douglas Fir; the effect of phenolic compounds on isolates of P. weiri; the tannins and ferulic, vanillic and caffeic acids in roots, leaves, litter and soil of Red Alder and Douglas Fir; soil tannins under Alder and conifers; and the characteristics of a compound, inhibitory to P. weiri, extracted from leaves of Red Alder but absent from Douglas Fir." (FA)

334. Lines, R.  
1976. Alnus rubra. In Report on forest research, Forestry Commission, ended for year 1976 in March, p. 16. Edinburgh, U.K.

"Experiments were planted in early 1976 with nine provenances of Alnus rubra and one of Alnus sinuata at Shin Forest (Highland Region) and Keilder Forest (Northumberland). Apart from the Alaskan provenance, all grew well in their second year in the nursery, and autumn shoot die-back was minimal, even on the Californian origin. Bacterial nodules had already formed on their roots." (A)

335. Little, Elbert L., Jr.  
1953. Check list of native and naturalized trees of the United States (including Alaska). U.S. Dep. Agric. Agric. Handb. 41, 472 p. Washington, D.C.
- superior height growth of A. rubra X A. glutinosa compared with A. glutinosa during the first 7 years and probable future developments, concluding that the hybrid will reach a height of 20 m. at 22-24 years and A. glutinosa at 40." (FA)
336. Little, Gene R.  
1978. Supply of western alder stumpage, its quantity and quality, and trends in alder stumpage prices and product markets for the State of Washington. In Utilization and management of alder, p. 9-23. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- "There is a sufficient supply of alder for the foreseeable future. Most alder is in private ownership. There will be a tremendous surplus (four times the current harvest) during the 1980's and 1990's. The opportunities for price improvement don't look promising, so we do not see why anyone would intentionally grow alder. To create a favorable climate for the alder industry, attitudes about this species must change." (A)
337. Ljunger, Aake.  
1959. Al-och alförädling. [Alder and alder breeding.] Skogen 46(5):115-117. [In Swedish.]
- "Discusses the two species found in Sweden, their ecology and silvicultural importance and the occurrence of hybrids, and presents figures from breeding experiments showing in graphs the
338. Lloyd, W. J.  
1949. Results of thinning a young alder stand. U.S. Dep. Agric. Soil Conserv. Serv., Pac. Reg. Tech. Note 8, 2 p. Portland, Oreg.
339. Lloyd, W. J.  
1952. Alder thinning, second progress report. U.S. Dep. Agric. Soil Conserv. Serv., Pac. Reg. Tech. Note 29, 2 p. Portland, Oreg.
340. Lloyd, William J.  
1955. Alder thinning-progress report. U.S. Dep. Agric. Soil Conserv. Serv., West Area Woodland Conserv. Tech. Note 3, 6 p. Portland, Oreg.
341. Lowe, Daphne P.  
1969. Check list and host index of bacteria, fungi, and mistletoes of British Columbia. Dep. Fish. and For., Inf. Rep. BC-X-32, 392 p. Victoria, B.C.
- Cross-indexed listing of British Columbia host genera and their attacking pathogens and saprobes. (CFH)

342. Lu, K. C., C. S. Chen, and W. B. Bollen.  
1968. Comparison of microbial populations between red alder and conifer soils. In *Biology of alder*, p. 173-178. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Seasonal populations of molds and bacteria in the F layer and All soil horizon from stands of pure conifers, pure red alder, and conifer-alder mixtures near the Oregon coast were compared by dilution plating techniques. All organisms were generally more numerous in the F layer than in the All horizon. On this very moist site, populations of molds were lowest in spring, when the soil was extremely wet. In the F layer, Streptomyces species, of particular interest due to their possible antagonism against root pathogens, consistently comprised a higher proportion of the total bacterial population of the mixed stand than of either pure alder or pure conifer stands." (A)

343. Lumberman.  
1955. Alder assumes importance and is discussed by foresters at 34th Washington State Forestry Conference. Lumberman 82(13):87, 129.

"Summarizes very briefly papers and discussion on uses of Red Alder [Alnus rubra] for pulping, timber and paneling, its seasoning, logging methods, natural regeneration, increment, epicormic branches and their effect on quality, soil relations, and rotation." (FA)

344. Lumberman  
1957. Alder logs find use in plugging newsprint rolls. Lumberman 84(7):46.

"Although many substitutes have been tried, the old standby--the wooden plug--remains today the most efficient and economical means of preventing newsprint rolls from collapsing or crushing on the core. This article tells how they are made from alder by a new company in British Columbia." (A)

345. Lutz, J. F.  
1972. Veneer species that grow in the United States. USDA For. Serv. Res. Pap. FPL-167, 127 p. For. Prod. Lab., Madison, Wis.

"Describes properties of 156 U.S. tree species that affect their manufacture and use as veneer or products made from veneer. Each species is rated for use in the general categories of construction plywood, decorative face veneer, inner plies of decorative panels, or container veneer and plywood." (A)

346. Lyons, C. P.  
1969. Trees, shrubs, and flowers to know in British Columbia. 2d ed. 194 p. J. M. Dent & Sons (Can.) Ltd., Toronto and Vancouver.

347. McCartney, William D., Robert F. Scharpf, and Frank G. Hawksworth. 1973. Additional hosts of Viscum album, European mistletoe, in California. *Plant Dis. Rep.* 57(10):904.

"Reports Alnus rubra, Populus fremontii, and Salix lasiandra as new hosts native to California. On the basis of inoculation tests, Populus tremuloides was also found to be susceptible. Ten other trees listed are ornamentals." (FA)

348. MacConnell, J. T. 1959. The oxygen factor in the development of function of the root nodules of alder. *Ann. Bot. (London) N.S.* 23(90):261-268.

The number of nodules of Alnus glutinosa growing in solution was reduced as the percent of oxygen in aerating gas was decreased. The nodulated plant was sensitive to oxygen reduction. It is concluded that oxygen supply is of special importance in the development and function of alder root nodules. (CFH)

349. McGovern, J. N., and G. H. McGregor. 1944. Sulfite pulp production: Some factors pertinent to meeting war born shortages. *Pulp and Pap. Mag. Can.* 45:74-81.

"The prospect of a serious shortage of sulphite pulp in 1944 prompted the Forest Products Laboratory, Madison, to survey ways and means of increasing pulp production under existing conditions. It is suggested that the less common pulpwood species together with logging, sawmill, and veneer-mill wastes be utilized to the full extent of their availability; that advantage be taken of dense woods giving high yield per

volume; that the pulping process be conducted in conformity with principles resulting in maximum production; and that fibre losses from chip preparation and pulp treatment and bleaching be minimised. The paper discusses briefly the pulping procedures applicable to species less commonly used for sulphite pulping, including Aspen, Cottonwood, Birch, Maple, Gum, Beech, Northern Pines, Tamarack, Western Pine, Larch, Douglas Fir, Southern Pine, Western Red Cedar, Sitka Spruce, and Alder, and examines in detail the sulphite process variables affecting pulp production. General observations are made on methods of reducing fibre losses due to different causes." (FA)

350. McGovern, J. N., J. S. Martin, and R. M. Kingsbury. 1951. Semichemical pulping characteristics of Pacific coast red alder, Douglas-fir, western redcedar, and western hemlock. *U.S. For. Prod. Lab. Rep.* R1912, 10 p. Madison, Wis.

"The alder gave neutral sulphite pulps suitable for container boards and bleached-paper products. Pulps made from Western Red Cedar and Western Hemlock had considerable promise for use in paper-board, that made from Douglas Fir somewhat less promise. Sulphate semichemical pulps made from Alder and old-growth Douglas Fir had lower chemical requirements, lower bursting strength and higher folding endurance than their neutral counterparts. Strong, bleached, neutral sulphite pulps can be produced in yields of 55% from Alder and 50% from second-growth Douglas Fir." (FA)

351. McGuane, Harry.

1978. Alder as a wood for veneer and plywood. (Abstr.) In Utilization and management of alder, p. 133. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The oral presentation described the process of manufacturing alder veneer in a facility equipped with the only hardwood lathe in the West. The hardwood lathe is equipped with a fixed nose bar which is capable of achieving higher peeling pressures than conifer lathes equipped with a roller bar. The capability of achieving higher pressures is important in controlling the roughness, depth of checks, and thickness of the veneer. The end product is a dry veneer that is 1/24 inch in thickness. The majority of this veneer is used in the manufacture of quarter inch plywood wall paneling.

"The market for alder veneer and its future are uncertain. Production of alder veneer has been low, and logs are frequently knotty so recovery of higher grades is difficult and costly. A large fraction is, therefore, a lower quality veneer which enters a very competitive market with surplus low quality veneers from other species. Style changes in the panelling industry and lack of familiarity with alder are other problems." (A)

352. McKelvey, Susan Delano.

1955. Botanical exploration of the Trans-Mississippi West 1790-1850. 1144 p. Arnold Arbor. Harvard Univ., Jamaica Plain, Mass.

Contains excerpts from original journals and edited journals of early botanists who collected plants in the Pacific Northwest. An alder was seen at Monterey Bay in 1791 by the Melaspina expedition.

Red alder was collected by Archibald Menzies in 1792 at Port Discovery, Washington, by Lewis and Clark in 1805 near the Dalls, Oregon, and by Douglas in 1825 at the mouth of the Columbia River. Nuttall describes red alder after collecting it in 1834. (CFH)

353. McLaughlin, Willard T., and Robert L. Brown.

1942. Controlling coastal sand dunes in the Pacific Northwest. U.S. Dep. Agric. Circ. 660, 46 p. Washington, D.C.

"An account of methods employed in arresting sand dunes at the mouth of the Columbia River, Oregon. ...The first stage in reclamation is the planting of sand-binding beachgrass, but final control requires the use of shrubs and trees, which may be introduced only after the initial stabilization has been accomplished. Scotch Broom (Cytisus scoparius (L.) Link) is the shrub most commonly employed for this purpose. The only native tree species used extensively in dune-control plantings is Shore Pine (Pinus contorta Loud.). The Pine is usually planted towards the inside of the dune where greatest height is needed, the Broom being planted on the outside where there is no heavy shade. Being a legume, the Broom builds up the nitrogen content of the soil while acting as a windbreak for the young Pines. Other trees used in the later stages of dune-reclamation include the introduced species Pinus pinaster, P. sylvestris, P. pungens, P. nigra, and Alnus glutinosa. (FA)

Red alder does not afford much winter protection and is useful only in damp areas. (CFH)

354. McMinn, Howard E., and Evelyn Maino. 1937. An illustrated manual of Pacific coast trees. 409 p. Univ. Calif. Press, Berkeley.

Red alder is identified as Alnus oregona. (CFH)

355. McMunn, H. I. 1956. Developing new uses for alder. Pac. Coast Hardwoods, March, p. 8-9. Northwest Hardwoods Assoc., Seattle, Wash.

Early efforts of one timber company to develop new products and sales of red alder. (CFH)

356. McNair, Cliff, Jr. 1973. Port Gamble turns to alder operations. Bremerton Sun, March 29, 1973, p. 1, col. 5-6; p. 2, col. 4-5.

357. McPherson, W. E. 1956. Wholesaling of Northwest hardwoods. Pac. Coast Hardwoods, March, p. 6-7. Northwest Hardwoods Assoc., Seattle, Wash.

358. McVean, D. N. 1953. Regional variation of Alnus glutinosa (L.) Gaertn. in Britain. Watsonia 3(1):26-32.

"Data from 18 populations show that Alder in Britain exhibits clinal variations in some features of its morphology and physiology, and that these variations tend to take place along the main climatic gradient S.E.-N.W. The fact

that no similar morphological gradients could be established altitudinally supports the theory that the differences are genotypic." (FA)

359. McVean, D. N. 1955. Ecology of Alnus glutinosa (L.) Gaertn. I. Fruit formation. J. Ecol. 43(1):46-60.

"The extent to which fruiting periodicity occurs in the Alder is described. Dates are given for the stages of fruit development, and the vulnerability of the ♂ nuclei in the extended period of 4-5 months between pollination and fertilization is stressed. Empty seeds are the result of fertilization failure rather than abortion. East Anglian Alders are shown to be completely self-sterile, and this, rather than frost damage to flowers, is regarded as a possible reason for low seed viability in certain years. High winds at the time of flowering are the most likely cause of low fertility in exposed populations and of the decreased % of embryo formation with increased altitude. Even in good seed years, embryos are not formed at altitudes above 300 m." (A)

360. McVean, D. N. 1955. Ecology of Alnus glutinosa (L.) Gaertn. II. Seed distribution and germination. J. Ecol. 43(1):61-71.

"Running water and wind-drift over standing water are shown to be the chief agents of dispersal, with important effects on seedling establishment and the form of populations. There is considerable variation (0-80%) in the viability of the seed set, and low viability is almost wholly due to the failure of embryo formation. Optimum

germination takes place at about 26° C and is independent of light, normal temperature fluctuations, and pH of the substrate. High O tension and humidity in the surrounding air are necessary for satisfactory germination. Cold treatment of damp seeds at 0-4° C for at least 6 weeks reduces the minimum germination temperature from 18 to 7° C; this has important ecological implications. The course of germination is described for laboratory and field seedlings. An important feature is the relative weakness of the radicle elongation and the liability of the radicle to suffer damage by low temperatures and incipient drying in the early stages of germination. This partly explains the hydrophytic behaviour of the species." (A)

361. McVean, D. N.

1956. Ecology of Alnus glutinosa (L.) Gaertn. III. Seedling establishment. J. Ecol. 44(1):195-218.

"Experiments on the relations of seedlings to soil moisture are described, Betula pubescens being used for comparison: (1) Seedling establishment in waterlogged soil. (2) Effect of waterlogging at various developmental stages. (3) Establishment at various heights above a constant water-table. (4) Effect of periodic drying of the soil. It is concluded that in regions of low rainfall (50-65 cm.) Alder seedlings will only establish themselves where the surface soil falls within the capillary fringe of the water-table, so that it remains constantly moist for 20-30 days in spring (March-May). Heavier rainfall and a cover of vegetation modify this picture. The Alder seedling is better adapted to establishment in very wet and waterlogged soils than is the Birch, and pure stands of Alder can be obtained from mixed sowings

by appropriate treatment. It is also more resistant to complete inundation at all stages of development. A water-table at a depth of 10-30 cm. is optimal for early Alder establishment, but subsequent growth is best on drier sites. The Birch seedling is better adapted to establishment in habitats subject to periodic drying out, and pure stands of Birch can thus be obtained by flooding. The different buoyancies of the seed, the different susceptibilities of the radicles to drying out, and the different ratios of shoot to root development are all concerned in this.

"The growth of seedlings on different soils is described, and establishment found to be satisfactory on all except acid peats and highly calcareous soils. Pure fen peat appears to lack some factor, present in mineral soil, necessary for the optimum development of the seedlings. An experiment on the addition of various fertilizers to the peat indicated that the phosphate radical is largely concerned. Development of nodules and mycorrhiza is found to have little effect on establishment except perhaps on the most infertile sands. Field and pot experiments on light intensity and root competition are described. It is concluded that low light intensity, supplemented by insect attack, flooding etc. is a frequent cause of regeneration failure in woods and thick herbaceous vegetation. Root competition appears to be of greatest importance in the drier grass turfs. The significance of these factors in natural population structures and succession is briefly discussed." (A)

362. McVean, D. N.

1956. Ecology of Alnus glutinosa (L.) Gaertn. IV. Root system. J. Ecol. 44(1):219-225.

"Analysis of the gas contained in Alder roots from below the soil water-table is described and the results shown to be comparable with those obtained by other workers on the submerged parts of herbaceous aquatics. The gas is largely contained in the xylem elements as in the genus Aeschynomene. The structure of the water lenticles on stems, roots and nodules is described and the suggestion made that they may play an important part in the root aeration mechanism of the species when growing on water-logged sites. Root-cutting experiments to test the importance of different parts of the root system in the water supply of the tree have shown that the deep tap roots may well account for the success of established Alder on sites of deep water-table. The importance of the surface system (with its nodules and mycorrhiza) in the nutrition of the tree on infertile soils was also demonstrated by this method." (FA)

363. McVean, D. N.

1956. Ecology of Alnus glutinosa (L.) Gaertn. V. Notes on some British alder populations. J. Ecol. 44(2):321-330.

"Describes Alder populations in the New Forest, Norfolk, N. Wales, Sutherland and Invernessshire. The details of floristics and succession are discussed. The Alderwood flora is influenced by the composition of the vegetation it had succeeded; 50% of Alderwood species are from fen and marsh associations and only 5% are woodland species. Alder communities are most distinct on wet sites rich in bases (the relationship of soil water

and base content to subordinate species is tabulated); on drier and less basic soils they merge with Oak, Ash, and Birch communities. The Alder colonizes hydroseres particularly quickly when fen successions have been deflected by mowing or grazing, but it does not invade grassland. It is suggested that the conditions required for a climax Alder carr are enough light and enough surface above water to permit regeneration from seed; it is unlikely that the community could be perpetuated by vegetative regeneration alone." (FA)

364. McVean, D. N.

1956. Ecology of Alnus glutinosa (L.) Gaertn. VI. Post-glacial history. J. Ecol. 44(3):331-333.

"Briefly discusses salient features in the European history of the Alder. Autecological studies indicate that the sudden increase of Alder pollen in the Late Boreal period was brought about by (1) a rise in the sea-level producing higher water-tables and initiating hydroseres, (2) and increased evaporation/precipitation ratio leading to a moist soil surface in spring which enabled the Alder to spread from one fen to another, and (3) climatic or biotic factors destroying the existing vegetation. Some evidence of recent climatic change in the British Isles, indicated by the structure and reproduction of hill Alder woods in the north and west, is presented." (FA)

365. Maas, E. F., and R. M. Adamson.  
1972. Resistance of sawdusts,  
peats, and bark to decomposition in  
the presence of soil and nutrient  
solution. *Soil Sci. Soc. Am. Proc.*  
36(5):769-772.

"Decomposition of organic growing media  
such as sawdust, bark or peat can have  
undesirable effects in the greenhouse  
culture of tomatoes. In this study the  
influence of (a) particle size of the  
medium, (b) nutrient additions (N, P, and  
K), and (c) an admixture of soil, was  
investigated by measuring weight losses  
in Alnus rubra sawdust, Pseudotsuga  
menziesii sawdust and bark, and three  
types of peat. The effect of (a) was  
small; (b) significantly increased  
decomposition of the sawdusts but had  
less effect on the bark; and (c) greatly  
increased decomposition in all the  
media." (FA)

366. Mackintosh, Anne H., and G. Bond.  
1970. Diversity in the nodular  
endophytes of Alnus and Myrica.  
*Phyton* 27(1):79-90.

"In the genera Alnus and Myrica respectively 17 and 12 unusual combinations of nodule endophytes and host species have been studied for symbiotic performance. In Alnus 9 of these combinations resulted in satisfactory symbioses, but in Myrica only one. It is concluded that the Alnus endophyte exists in a number of forms, each able to symbiose with a restricted number of unusual host species, but that in Myrica the endophytes show little or no such ability. Geographical distribution and taxonomic affinity of host species provide a rational basis for some of the findings." (A)

367. Madison, Robert W.  
1957. A guide to the Cascade Head  
Experimental Forest. USDA For.  
Serv. Pac. Northwest For. and Range  
Exp. Stn., 13 p. Portland, Oreg.

"Describes the experimental forest, its  
purposes and administration, and the  
research projects in progress." (A)

368. Madison, Robert W., and Robert H.  
Ruth.  
1962. Basal spraying of red alder.  
*Weeds* 10(4):324-325.

"Red alder (Alnus rubra) was readily  
killed by growing-season treatments with  
a 1 to 1 mixture of 2,4-dichloro-  
phenoxyacetic acid (2,4-D) and 2,4,5-  
trichlorophenoxyacetic acid (2,4,5-T) in  
diesel oil. Except for 1-inch-diameter  
trees, it was resistant to dormant-season  
treatments. Treatments applied during  
moderate rain were less effective than  
during rain-free periods." (BA)

369. Maloney, T. M.  
1978. Alder: One of tomorrow's  
important structural raw materials?  
In Utilization and management of  
alder, p. 125-132. David G. Briggs,  
Dean S. DeBell, and William A.  
Atkinson, compilers. USDA For.  
Serv. Gen. Tech. Rep. PNW-70. Pac.  
Northwest For. and Range Exp. Stn.,  
Portland, Oreg.

"Alder is a lightweight, fast-growing  
species ideally suited for composition  
board and composite materials. Studies  
indicate that there will be a shortage  
of conventional raw material for plywood  
building materials in the Pacific Northwest.  
The composite panel made of veneer  
faces and a particleboard core offers a

building panel that can possibly use alder for core. Plywood plants can maintain or increase their production rate using particleboard cores, thus avoiding problems associated with shortages of conventional veneer.

"Demonstration alder flakeboards (a type of particleboard) showed excellent modulus of rupture, modulus of elasticity, and internal bond properties which exceeded those in competitive flake-type boards. Indications are that alder merits serious consideration as a raw material for structural panel materials (composition board and composites)." (A)

370. Manolis, B.  
1975. Coastal mixed forest. Am. Birds 29(3):767.

Results of a bird survey in a coastal mixed forest at Point Reyes, California. Red alder was the most abundant tree species. Twenty species were observed at a density of 1,702 birds per square kilometer. (CFH)

371. Maranville, L. Frank, and Otto Goldschmid.  
1954. Ultraviolet absorption spectra as a measure of phenolic hydroxyl group content in polyphenolic tanninlike materials. Anal. Chem. 26(9):1423-1427.

"A rapid and simple method for determination of phenolic groups in natural polyphenolic materials, such as tannins, has long been needed. An ultraviolet spectrophotometric method employing difference [sic] spectra has been developed which is suitable for this determination. Results by the spectrophotometric method are compared with

those by purely chemical 2,4-dinitrophenyl ether method. Values obtained by both methods on a series of bark extracts of several species of softwood and hardwood trees are in qualitative agreement. The ultraviolet procedure is an extremely rapid and convenient method for obtaining a relative measure of the phenolic content of natural polyphenolic materials and provides a convenient means of differentiating different classes of such materials." (A)

372. Margolin, Malcom.  
1974. Hurray for alder, scourge of the woods. Living Wilderness 38(125):36-42.

Virtues of alder described in layman's language. Arguments are made for promoting alder management regimes. (CFH)

373. Markwardt, L. J., and T. R. C. Wilson.  
1935. Strength and related properties of woods grown in the United States. U.S. Dep. Agric. Tech. Bull. 479, 99 p. Washington, D.C.

374. Marple's Business Newsletter.  
1974. Wood chips are in tight supply. Marple's Business News. 643, p. 3-4.

"Wood chips are in tight supply now because pulp mills are running at capacity while lumber and plywood plants, a source of by-product chips, have cut back. The price has about doubled in a year. Early this year when Japanese mills got behind in their hardwood requirements, alder went to a premium over Douglas-fir. Clean alder chips from whole logs now bring \$60 a unit, and those from whole-tree chipping (with up to 12% bark and other residue), about \$55. Pope & Talbot will sell its Port Gamble chips to paper mills on Puget Sound." (A)

375. Matthewes, Rolf W.  
1973. A palynological study of postglacial vegetation changes in the University Research Forest, southwestern British Columbia. Can. J. Bot. 51(11):2085-2103.

"The postglacial vegetation history of the University of British Columbia Research Forest was investigated using percentage and absolute pollen analysis, macrofossil analysis, and radiocarbon dating. A marine silty clay deposit records the oldest ( $12,690 \pm 190$  years before present (B.P.)) assemblage of terrestrial plant remains so far recovered from the postglacial of south-coastal British Columbia. Lodgepole pine (Pinus contorta) dominated this early vegetation, although some Abies, Picea, Alnus and herbs were also present. Sediment cores from two lakes were also studied. The older is Marion Lake, where five pollen assemblage zones are recognized, beginning with a previously undescribed

assemblage of Pinus contorta, Salix, and Shepherdia in clay older than  $12,350 + 190$  B.P. The pollen diagram from Surprise Lake ( $11,230 \pm 230$  B.P.) is divided into three pollen zones which show the same major trends of vegetation change as the Marion Lake diagram.

"The first report of the postglacial vegetation history of cedar (Thuja and perhaps Chamaecyparis) in southwestern British Columbia is presented from Pollen and macrofossil analyses.

"At about 10,500 B.P. in both lakes, pollen of Douglas-fir (Pseudotsuga menziesii) began a rapid increase, probably in response to climatic amelioration. The palynological evidence, supported by well-preserved bryophyte subfossils, suggest that humid coastal conditions have prevailed in the study area since about 10,500 B.P., with virtually no evidence for a classical Hypsithermal interval between 8500 B.P. and 3000 B.P." (A)

376. Matthews, Oliver V.  
1941. Something new among the alders. Am. For. 47(8):374-377, 400.

Reports several cut-leaved red alder at various locations in the Pacific Northwest. (CFH)

377. Menzies, Archibald.  
1923. Menzies' journal of Vancouver's voyage. April to October 1792. Edited, with botanical and ethnological notes by C. F. Newcombe, M.D., and a biographical note by J. Forsyth. Mem. V. Arch. B.C. Victoria.

Menzies was the first person to collect plants from the Pacific Northwest. He did not describe his own collections.

Apparently many of the species collected have not been studied yet. Red alder appears to be one of these. On May 1, 1792, Vancouver made his first landing in a region that later was to become the United States. This was on an island in the strait of Juan de Fuca at the entrance to Port Discovery, Jefferson County, Washington. They named it Protection Island.

On May 2, Menzies went ashore with Captain Vancouver. He wrote in his journal: "Besides a variety of Pines we saw the Sycamore Maple [Acer Macrophyllum] - the American Alder [Alnus oregonia] - a species of Wild Crab [Pyrus diversifolia] and the Oriental Strawberry Tree [Arbutus menziesii] ... - We met with some other Plants which were new to me ...". (CFH)

378. Mestre, J. C.

1964. [Embryogeny of the Amentaceae. Development of the embryo of Alnus glutinosa.] C. R. Acad. Sci., Paris 258(24):5949-5951.

The morphology of development of the embryo Alnus glutinosa L. is basically the same as that of Senecio vulgaris. It departs from it, however, by the presence of a true hypophysis which furnishes the suspensor stage. This embryonic type should then be linked to the Calendula arvensis type. (CFH)

379. Metcalf, Melvin E.

1965. Hardwood timber resources of the Douglas-fir subregion. USDA For. Serv. Resour. Bull. PNW-11, 12 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Gives statistics, adjusted for 1963, from inventories of Alnus rubra, Acer macrophyllum, and Populus trichocarpa, with some data on other hardwoods."

380. Miller, James H.

1974. Nutrient losses and nitrogen mineralization on forested watersheds in Oregon's Coast Range. Ph. D. thesis. Sch. For., Oreg. State Univ., Corvallis. 94 p.

"Nutrient losses of the biologically responsive anions, nitrate and bicarbonate together with the major cations, were monitored on 14 small watersheds in Oregon's Coast Range and evaluated in relation to management-induced disturbance. Mixed forests of Douglas-fir and red alder had dominated these high-nitrogen sites prior to treatment.

"During the approximately two years of streamwater monitoring following treatments, no significant increases in dissolved solids were observed. No consistent differences appeared between treatments or between cut and uncut watersheds. Nitrate concentrations (2.8 ppm N maximum) never exceeded U.S. Public Health Service (1962) standards for drinking water.

"Nitrification rates are substantially greater in alder soils; while ammonification rates appear similar for the two soils within the normal operating regimes of temperature and moisture. In a very wet alder soils the mobile nitrate anion is reduced to the less mobile ammonium cation and ammonification rates are minimal. This behavior appears to be important in nutrient retention during winter flushings when high soil moisture is prevalent in the lower soil profile and in wet source areas (slowly draining areas) that characterize parts of these watersheds.

"The combinations of temperature and moisture exhibiting the highest rates of nitrogen mineralization (suggesting unstable states) were not encountered in the field under stands or in cleared situations. Soil temperatures above 21° C combined with moist but unsaturated conditions results in the highest rates of nitrate production. This, and the observed behavior of the nitrogen-rich watersheds, suggest that nitrate losses in streamwater following forest disturbance are only likely in climatic regions of summer-surplus precipitation." (A)

381. Miller, Richard E., and Marshall D. Murray.

1978. The effects of red alder on growth of Douglas-fir. In Utilization and management of alder, p. 283-306. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"We describe the long-term effects of off-site red alder that were interplanted in 1933 within a 4-year-old Douglas-fir plantation in southwestern Washington. Insufficient available nitrogen limits tree growth in this plantation. Red alder clearly increased height and diameter of the associated dominant Douglas-fir. Improved growth in diameter began when the Douglas-fir emerged through the alder canopy. This emergence occurred at about 30 years from seed at Wind River and in several even-aged, mixed stands that we also investigated. By age 48, Douglas-fir volume per acre in the mixed stand averaged about 3,100 cubic feet compared to 2,900 cubic feet

in the pure stand. Red alder volume was about 2,500 cubic feet. Maintaining red alder in Douglas-fir stands can increase merchantable yields on nitrogen-deficient sites. Controlling stand density at an early age is necessary to maintain both Douglas-fir and alder in a dominant or codominant position. To provide adequate nitrogen and not seriously reduce Douglas-fir growing stock, about 20 to 40 uniformly distributed red alder per acre should be retained." (A)

382. Minore, Don.

1966. Identification of rotten logs in the coastal forests of Oregon and Washington. 16 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Provides an identification key to rotted logs and species description for red alder. (CFH)

383. Minore, Don.

1968. Effects of artificial flooding on seedling survival and growth of six northwestern tree species. USDA For. Serv. Res. Note PNW-92, 12 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Winter flooding in tanks in Jan. 1967 of seedlings from seed germinated in April 1966, for periods of 1-4 weeks, severely injured Pseudotsuga menziesii but had little effect on the other species. Summer flooding from June 1967 for 4 and 8 weeks affected all species; many seedlings died and many formed adventitious roots at the water-line. Thuja plicata and Pinus contorta seemed to be the most tolerant, and Pseudotsuga menziesii to be extremely intolerant, of flooding; Alnus rubra, Picea sitchensis and Tsuga heterophylla were intermediate." (FA)

384. Minore, Don.

1970. Seedling growth of eight northwestern tree species over three water tables. USDA For. Serv. Res. Note PNW-115, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Seed was sown in pots with soil of uniform texture, and water-table depth was controlled at (a) 7.5, (b) 35.5 and (c) 66 cm (techniques described and illustrated). Results indicate that Pinus contorta, Thuja plicata, Alnus rubra and Picea sitchensis are all tolerant, and Pseudotsuga menziesii intolerant, of (a); P. contorta and T. plicata grew best over (c). Tsuga heterophylla and Abies amabilis were not significantly affected by depth of the water table." (FA)

385. Minore, Don.

1972. Germination and early growth of coastal tree species on organic seed beds. USDA For. Serv. Res. Pap. PNW-135, 18 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Gives the results of field observations and field and laboratory experiments in Oregon on Pseudotsuga menziesii, Picea sitchensis, Tsuga heterophylla, Thuja plicata, Pinus contorta, Abies amabilis, and Alnus rubra, including information on the effects of shading. Nutrients were more abundant in duff (litter/humus) than in rotted wood. In dense coastal stands, seedlings were usually larger and more abundant on duff-covered rotten logs than on duff-covered mineral soil, because the duff accumulations were thicker on logs and over rotten wood

embedded in the soil than over mineral soil alone. Shade limited root growth more than height growth, but seedbed differences limited height growth more than root growth. All conifer species responded similarly to the seedbed and shade differences tested, and it is concluded that the type of organic seedbed probably does not affect the species composition of forest regeneration under lightly thinned shelterwoods in this area." (FA)

386. Minore, Don, and Clark E. Smith.

1971. Occurrence and growth of four northwestern tree species over shallow water tables. USDA For. Serv. Res. Note PNW-160, 9 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The occurrence and radial growth of (a) Alnus rubra, (b) Thuja plicata, (c) Picea sitchensis and (d) Tsuga heterophylla were related to estimated water-table depths in swamps in the Olympic Peninsula, Washington. Fifty-six plots, each consisting of a line intercept 6-15 m long, were established on sites where undisturbed native trees and Lysichitum americanum were found growing together. The petiole length of L. americanum were used as an indicator of water-table depths. All four tree species were found to tolerate winter water tables at >15 cm depth. Where the water table was <15 cm deep, and (a) and (c) grew well with flowing groundwater, and (a) and (b) grew well with stagnant water; (d), however, appeared to be intolerant of water tables shallower than 15 cm." (FA)

387. Minore, Don, Clark E. Smith, and Robert F. Woollard.  
1969. Effects of high soil density on seedling root growth of seven northwestern tree species. USDA For. Serv. Res. Note PNW-112, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Pseudotsuga menziesii, Picea sitchensis, Tsuga heterophylla, Thuja plicata, Pinus contorta, Abies amabilis, and Alnus rubra were grown in plastic pipes in soils of three degrees of compaction--1.32, 1.45, and 1.59 g./c.c. Seedlings weights and root depths are tabulated. Total weights, root and shoot weight, and maximum root depths are influenced by differences in available nutrients. Average root depths, however, show that P. menziesii, P. contorta, and A. rubra can penetrate soil densities that inhibit roots of P. sitchensis, T. heterophylla, and T. plicata. A. amabilis ranks between the two groups." (FA)

388. Mitchell, Harry O.  
1958. Pacific coast hardwoods and their uses. Natl. Hardwood Mag. 32(11):110-114.

Talks about alder's uses as veneer, solid wall paneling, fine furniture, kitchen cabinets, flooring, tanned products, chairs, pattern stock, and other miscellaneous uses. (CFH)

389. Moravets, F. L.  
1956. Oregon's hardwood resources. Pac. Coast Hardwoods, March, p. 12-13. Northwest Hardwood Assoc., Seattle, Wash.

Red alder is the most abundant of Oregon's hardwood species and is found in all 19 counties west of the Cascade Range. There are 215,000 acres of alder type in western Oregon. Total sawtimber volume of red alder is estimated at 3.9 billion board feet. (CFH)

390. Morrison, Vance L.  
1949. Keeping roads alder free by the use of chemical sprays. B.C. Lumberman 33(1):108-110.

"The Oregon State Board of Forestry in cooperation with the Crown-Zellerbach Corporation has experimented with chemical sprays used for controlling the encroachment of brush (particularly Alder) on roads in Western Oregon. Chemical use were isopropyl ester and alkanolamine salt, both derivatives of 2,4,-D which were applied at the rate of about 4 gal. per acre. After 6 weeks 90% of Alder under 10 ft. high was apparently killed, and a pruning effect was observed on the large Alder. The experiments were not conclusive, but the following points emerge from reports by various other organizations: (1) 2,4-D kills by entering the stomata and working its way to the roots. If the outer stem and leaves are killed before the chemical reaches the roots, or if the tree is large, or the application is too light,

the roots are not affected and the tree recovers. (2) Spraying should be done when the leaves have reached normal development, using any pumper with a pressure of 200-600 lb. A weak solution repeated after 2 weeks is better than one heavy application. (3) A height greater than 10 ft. should not be treated, unless a pruning effect only is required. (4) Cost estimates by different agencies vary between \$20.00 and \$50.00 per mile. (5) Fire hazard after treatment should not be very great since Alder tends to rot quickly." (FA)

391. Morse, William B.

1967. Don't call red alder a weed!  
Am. For. 73(9):38-40, 50-51.

392. Moshier, Bill.

1955. Farmers find alder can be profitable. Seattle Sunday Times, Mag. Sect., May 15, p. 23. Seattle, Wash.

393. Mothershead, John S., and Douglas W. Glennie.

1964. Chemical structure of lignin sulfonates. Part II. Identification of monomeric lignin sulfonates from red alder. Tappi 47(8):519-524.

"Monomeric lignin sulfonates from red alder wood were isolated and identified. A fraction containing lignin sulfonates with low molecular weight was obtained by precipitating components with higher molecular weight in 70 and 80% ethanol. Further separation was obtained by chromatography in a column on ion-exchange resin and magnesia-silica gel

adsorbent. Vinylsyringyl sulfonate appeared to be a major monomeric component which formed at least 4% of the total lignin sulfonates obtained in the first stage of sulfonation. It was the major product formed by sulfonating sinapyl alcohol. Also, evidence was found for presence of the monomers vinylvanillyl sulfonate, coniferyl sulfonate, and the sulfonates of coniferaldehyde and sinapaldehyde, and their identity confirmed by thin-layer chromatography. Formation of monomeric sulfonates from coniferyl and sinapyl alcohol or hydrated coniferyl and sinapyl alcohol units in lignin from red alder wood is proposed." (CA)

394. Muenscher, W. C.

1941. The flora of Whatcom County, State of Washington. 134 p.  
William A. Church Co., Ithaca, N.Y.

Red alder is one of the species discussed. (CFH)

395. Mulligan, Brian O., Compiler.

1977. Woody plants in the University of Washington Arboretum, Washington Park. 183 p. Coll. For. Resour., Univ. Wash. Seattle.

A checklist of the woody plants growing in the University of Washington Arboretum in Seattle. In addition to red alder, there are 31 other species, varieties, ornamental forms, and hybrids of alder present. (CFH)

396. Mullin, Sandy.

1978. New approaches to producing furniture components from hardwood lumber. (Abstr.) In Utilization and management of alder, p. 123. David G. Briggs, Dean S. DeBell, and William A Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Furniture dimension parts are currently being manufactured from red alder on both the East and West Coasts. Species characteristics and the location of standing timber give alder certain competitive advantages. Dimension manufacturers, however, must continue to use every means to reduce the unit costs of processing. This paper described mini-computer systems presently being used in furniture dimension plants to reduce lumber waste." (A)

397. Munch, E.

1936. Das Erlensterben. Forstwiss. Centralbl. 58(6):173-194.

"In many plantations red alder trees develop bushy forms and begin to bear heavy seed crops by the 3d yr. after planting; at about the 12th yr. they commence to die. This phenomenon was first reported in Germany by Ortzen, in Mecklenburg. Black alder plantations have failed since 1865; natural stands have done well. Since at least 1873 practically all alder plantations have been made with seed or plants of foreign, chiefly Belgian, origin. It is believed that this seed is not adapted to the German conditions and is less tolerant of low temps. and changes in ground water level than the native stock. Many

of the dying trees are attacked by Valsa oxystoma, but this is not the primary cause of death, for it seldom injures natural stands. In comparative plantings exps. at Tharandt with seed from native alder from East Prussia, Mecklenburg, and Saxony, and with seed of foreign alder (Belgian), the foreign stock in all cases grew faster for about 6 yrs., then more slowly than native stock. The foreign alder bore seed every year, beginning about the 4th yr., but native alder has not borne seed in 11 years. Similar results were obtained with birch from native and Belgian stock; the Belgian birch seeded abundantly every yr. after the 4th, but native birch begins after 10-30 yrs. and then seeds only about once in 3 yrs. There is danger that all seed available commercially will be from such "bred-down" races, for the tendency is to collect seed from the trees that bear soonest and most abundantly, although they are most susceptible to disease and climatic injury and have poor form. Experience with cherry (Prunus serotina) has been similar; most of that now grown in Germany is little better than a shrub but bears abundant seed at an early age. The author believes that the same principles apply to these and other spp. as have been demonstrated in the case of larch and Scotch pine; namely, that only native seed of parent trees known to be adapted to the locality where used should be employed in forestry operations." (BA)

398. Munger, Thornton T.

1938. Red alder long considered but a weed tree, now an important raw material for west coast woodworkers. Hardwood Record 76(3):7-8.

Survey of the distribution, silvics, and uses of red alder. (CFH)

399. Munns, E. N.  
 1938. The distribution of important forest trees of the United States. U.S. Dep. Agric. Misc. Publ. 287, 11 p. and 170 maps. Washington, D.C.
- Contains distribution map of red alder. (CFH)
400. Murai, Saburo.  
 1964. [Phytotaxonomic and geobotanical studies on genus Alnus in Japan, III--Taxonomy of whole world species and distribution of each section.] Gov. For. Exp. Stn. Bull. 171, 107 p. Tokyo. [In Japanese. English summary and captions.]
- A taxonomic work of major importance. Contains sufficient English to be useful. See Murai (401) for English version summarizing much of the information on red alder. Concludes that Alnus is divided into the subgenera Alnaster (now relegated to this rank; with sections Bifurcatus and Alnobetula) and Gymnothyrus (with sections Cremastogyne, Clethropsis, Japonica, Fauriae, and Glutinosae). Phylogeny is discussed with reference to morphology, distribution, and chromosome numbers. Spontaneous polyploidy is found in Bifurcatus. Diagnostic characters of species and varieties are illustrated. The hybrid A. x ljungeri (A. glutinosa x A. rubra) is most promising among intrasectional crosses. (CFH)
401. Murai, Saburo.  
 1968. Relationships of allied species between northwestern U.S.A. and Japan on the genus Alnus. In Biology of alder, p. 23-36. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- "In this paper the author has attempted to compare the genus Alnus in the northwestern United States with that in Japan. The results are reported herein; comments are solicited." (A)
402. Nagoda, Ludvik.  
 1968. Vanninnholdet hos trevirke og vektmaling. [Water content of wood and weight measurement (literature study)]. Tidsskr. Skogbruk 76(3):191-216.
- "Discusses the literature (with particular reference to Alder, Aspen and Birch) and includes sections on weights vs. volume measurements, variations in moisture content with position (radial or vertical) in the stem, season and site conditions, green density of freshly felled trees and changes in density during storage. It is concluded that green weight alone is inadequate as a basis for measurement but that weighing with a correction for dry-matter content, gives satisfactory results regardless of species, log size and season." (FA)

403. Neal, J. L., Jr., W. B. Bollen, and K. C. Lu.

1965. Influence of particle size on decomposition of red alder and Douglas fir sawdust in soil. *Nature* (London) 205(4975):991-993.

"Experiments made with sawdust in four particle-size ranges showed a definite parallelism between particle size and microbial activity: the smaller the particle, the greater the O consumption. The addition of  $\text{NH}_4\text{NO}_3$  with the various sawdust sizes did not stimulate O uptake, and in fact reduced it in some cases." (FA)

404. Neal, J. L., Jr., K. C. Lu, W. B. Bollen, and J. M. Trappe.

1968. A comparison of rhizosphere microfloras associated with mycorrhizae of red alder and Douglas-fir. In *Biology of alder*, p. 57-71. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Rhizosphere microfloras of Cenococcum graniforme (Sow.) Ferd. and Winge mycorrhiza of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), of one type of ectotrophic mycorrhiza of red alder (Alnus rubra Bong.), and of non-mycorrhizal suberized roots of both tree species were investigated. Microbial populations and the most probable numbers of ammonifying and nitrate-reducing microbes differed qualitatively and quantitatively between rhizosphere microhabitats. In manometric studies, homogenized Douglas-fir highly stimulated respiration of nonrhizosphere microbes, especially in the presence of glucose. Glucose oxidation, however, was suppressed in the presence of Douglas-fir

mycorrhizal root suspension, probably by the antibiotic which the fungal symbiont, C. graniforme, is reported to produce. Glucose oxidation by nonrhizosphere microbes was similarly repressed in the presence of red alder nonmycorrhizal root suspension. An antagonistic substance found in red alder root and nodule suspensions inhibited growth of Bacillus subtilis (Cohn) Prazmowski and B. cereus Frankland and Frankland on glucose-salts agar. These experimental results are discussed with reference to the influence of mycorrhizal and adjacent nonmycorrhizal suberized roots upon rhizosphere microfloras." (A)

405. Neal, J. L., Jr., K. C. Lu, J. M. Trappe, and W. B. Bollen.

1966. Rhizosphere microbial activity of mycorrhizal and nonmycorrhizal roots of Douglas fir and red alder. (Abstr.) *Bacteriol. Proc.* 1966(2):A10.

"More microorganisms were found in the rhizosphere of both species than in the non-rhizosphere soils. The difference was much greater in Red Alder than in Douglas Fir; in Alder there were ca. twice as many microorganisms in the rhizosphere of mycorrhizal roots than in that of suberized, nonmycorrhizal roots, but microorganisms were more frequent near nonmycorrhizal roots of Douglas Fir. Crushed mycorrhizae of Alder stimulated microbial growth *in vitro*. The mycorrhizae of Douglas Fir associated with Cenococcum graniforme had little or no stimulating effect, possibly because of the presence of antagonistic substances." (FA)

406. Neal, J. L., Jr., J. M. Trappe, K. C. Lu, and W. B. Bollen.  
1967. Sterilization of red alder seedcoats with hydrogen peroxide. *For. Sci.* 13(1):104-105.

"Concludes from data (tabulated) on the effect of duration of soaking in 30% H<sub>2</sub>O<sub>2</sub> on surface sterilization (s.s.) and germination (g.) of Alnus rubra seed, that soaking for 10 min. gives complete s.s. with optimum g. (52% after 14 days)." (FA)

407. Neal, J. L., Jr., J. M. Trappe, K. C. Lu, and W. B. Bollen.  
1968. Some ectotrophic mycorrhizae of Alnus rubra. In *Biology of alder*, p. 179-184. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Two forms of mycorrhizae predominated on root systems of red alder (Alnus rubra Bong.) in a pure stand near the Oregon coast. Detailed morphological studies, the first for this species, revealed distinct characteristic differences between fungal symbionts. The great abundance of these mycorrhizae and their immediate influence on rhizosphere microbes could markedly affect the incidence of root disease." (A)

408. Neal, John Lloyd, Jr.  
1968. Rhizosphere microfloras associated with mycorrhizae of Douglas-fir and red alder. Ph. D. thesis. Oreg. State Univ., Corvallis. 88 p.

"The mycorrhizal rootlets of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco.) and red alder (Alnus rubra Bong.) were extensively investigated. A jet-black

mycorrhiza was found to be dominant on Douglas-fir rootlets. The fungal symbiont was identified as Cenococcum graniforme (Sow.) Ferd. and Winge. Two forms of mycorrhizae predominated on root systems of red alder. Detailed morphological studies, the first for this alder species, revealed distinct characteristic differences between the fungal symbionts. One common mycorrhizal form was clavate with a dark-brown roughened fungal mantle. The Hartig net was well developed. The other predominant form was pale brown and glabrous. The Hartig net was weakly developed and sporadic.

"Rhizosphere microflora of three morphologically different mycorrhizae of a Douglas-fir were examined and compared with microflora surrounding adjacent suberized roots and with that in non-rhizosphere soil. Populations of bacteria, molds, and Streptomyces were different for each microhabitat." (A)

"Rhizosphere microfloras of Cenococcum graniforme mycorrhizae of Douglas-fir, of one type of ectotrophic mycorrhiza of red alder, and of non-mycorrhizal suberized roots of both tree species were investigated. Microbial populations and the most probable numbers of ammonifying and nitrate reducing microbes differed qualitatively and quantitatively among rhizosphere microhabitats.

"These experimental results are discussed with reference to the influence of mycorrhizal adjacent nonmycorrhizal suberized roots upon rhizosphere microfloras." (FA)

409. Nelson, E. E.

1968. Survival of Poria weiri in conifer, alder, and mixed conifer-alder stands. USDA For. Serv. Res. Note PNW-83, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Cubes of Douglas Fir heartwood naturally infected with P. weiri were buried for up to 18 months in stands of conifers, Alder (Alnus rubra) and mixed Alder and conifers. Survival of the fungus in the cubes was better under the pure conifers than under stands containing Alder, perhaps because many fungi, bacteria and actinomycetes competing with P. weiri for soil nutrients can, unlike P. weiri, use  $\text{NO}_3\text{-N}$  (present in large amounts under Alder.)." (FA)

410. Nelson, E. E.

1976. Effect of urea on Poria weiri and soil microbes in an artificial system. Soil Biol. and Biochem. 8(1):51-53.

"Reports a laboratory study on P. weiri established in small stem billets of Alder (Alnus rubra), buried in soil from a Pseudotsuga menziesii stand in Oregon and incubated in the dark at 15 deg C for 32 weeks. Results showed that no P. weiri survived in soil to which urea (147 or 294 g N/m<sup>3</sup>) had been added. The survival of P. weiri during the first 16 weeks was inversely correlated with urea dosage and with populations of Trichoderma (first observed after 8 weeks) and actinomycetes. Field plots have been established to ascertain whether P. weiri can be controlled in the field by N treatment, possibly combined with mechanical disruption of old root systems." (FA)

411. Nelson, E. E., and H. Fay.

1974. Thermal tolerance of Poria weiri. Can. J. For. Res. 4(3):288-290.

"P. weiri may survive for years in buried wood; temperature, interacting with the microflora, influences its longevity. When grown in stem sections of alder (Alnus sp.) and incubated while relatively free of competition from other fungi, P. weiri survived for 32 weeks at between -5 deg and +30 deg C; survival was reduced progressively when the fungus was subjected to greater extremes of cold (down to -20 deg) or heat (up to +39 deg). Pre-conditioning of stem sections colonized by P. weiri for 1 week at 65 deg improved subsequent survival at -15 deg. Though extreme heat or cold can thus be lethal to P. weiri, such conditions do not occur very deep in the soil within the geographic range of the fungus, and it is concluded that temperature is probably only an indirect factor in this survival in forest soils." (BA)

412. Nelson, E. E., E. M. Hansen, C. Y. Li, and J. M. Trappe.

1978. The role of red alder in reducing losses from laminated root rot. In Utilization and management of alder, p. 273-282. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Experiment Station, Portland, Oreg.

"Red alder, in mixture with conifer or preceding stands of conifers, may be useful in reducing damage from laminated root rot (Phellinus weiri) on infested sites. This benefit could result from changes in soil nitrate, pH, fatty acids, phenolic compounds and microbial populations brought about by alder, as well as

physical separation of susceptible root systems in mixed stands. Survey data tend to support this hypothesis. Disease incidence may be limited by reducing saprophytic survival of the pathogen or inhibiting its spread along conifer roots. Evidence for the former is greater than for the latter. Long-term experimental plots have been established to provide more definitive answers." (A)

413. Nelson, Earl E.

1970. Effects of nitrogen fertilizer on survival of Poria weirii and populations of soil fungi and aerobic actinomycetes. *Northwest Sci.* 44(2):102-106.

Examined effects of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  fertilization on the survival of Poria weirii in buried soil cubes. Field tests were inconclusive, but laboratory tests showed a relationship between nitrogen fertilization and P. weirii survival. (CFH)

414. Nelson, Earl E.

1975. Survival of Poria weirii on paired plots in alder and conifer stands. *Microbios* 12(49):155-158.

"Cubes of Douglas-fir wood decayed by Poria weirii (Murr.) Murr. were buried for 12 months on paired plots in red alder and in conifer soils on the Cascade Head Experimental Forest. Survival of the fungus was not significantly different in the two soils, although pH was significantly lower and nitrate content significantly higher in alder soils. Even though effects on fungus survival were nil, red alder, for other reasons, might still be used to reduce damage caused by P. weirii root rot on areas of heavy infestation." (A)

415. Nelson, Earl E.

1976. Colonization of wood disks initiated by basidiospores of Phellinus weirii (laminated root rot). *For. Sci.* 22(4):407-411.

"Suspensions of basidiospores of Phellinus [Inonotus] weirii at concentrations from 80 to 50,000 spores/ml were sprayed on to previously frozen and scalded wood discs of 9 species of softwood and 2 species of hardwood, and incubated at 5, 10, 15, 20° C with a spore concentration of 400/ml. Discs first sprayed with a soil suspension or buried after inoculation were not colonized by I. weirii. Thuja plicata, Picea sitchensis, Acer macrophyllum and Alnus rubra were resistant to colonization, the latter two not being hosts of the fungus. Sapwood of Pseudotsuga menziesii was colonized more than heartwood." (FA)

416. New Zealand State Forest Service.

1944. Annual report of the Director of Forestry for the year ended 31st March, 1944. 38 p. Gov. Print., Wellington.

"Observations made on plots of exotic conifers planted during 1927-29 at high altitudes (2,200-3,800 ft. above sea-level) under exposed conditions on the central North Island Plateau, showed Pinus murrayana and P. ponderosa to be the most thrifty species followed by P. austriaca, P. sylvestris, P. banksiana, P. rigida and P. strobus. Other species, including P. radiata, gave poor results. Trees of all species are heavily branched and of poor timber form, but the study

gives a good indication of the species most suitable for the extension of upland protection forests.

"In an experimental interplanting of worked Podocarp forest with exotic hardwoods, two South American Beeches (Nothofagus procera and N. obliqua) and Red Alder (Alnus rubra) showed particularly good height growth and development." (FA)

417. Newton, M.

1966. New injection system for killing or curing trees. (Abstr.) Meet. Weed Soc. Am. 1966:30-31.

"The Hypo-Hatchet is a precision instrument, weighing ca. 3 lb., that operates automatically on impact. The chemical reservoir is of light-weight plastic and when full (2.5 lb.) should last half a day at rates of 0.5 ml. per cut. The positive-displacement pump is self-priming and will feed if the reservoir is below the instrument. The dosage may be calibrated to deliver any volume up to 1 ml. The instrument, using undiluted compounds for 0.5 ml. injections spaced 3, 6 or 9 in. apart, has given consistent control of a variety of hardwoods and conifers, including Pseudotsuga menziesii, Abies grandis, Tsuga heterophylla and Prunus spp. with cacodylic acid or picloram + 2,4-D; Picea sitchensis, Acer rubrum and Alnus rubra with 2,4-D amine; and A. macrophyllum with picloram or fenoprop K. The instrument may also be used for precision injection of antibiotics and insecticides." (FA)

418. Newton, Michael.

1978. Herbicides in alder management and control. In Utilization and management of alder, p. 223-230. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Herbicides can be used effectively to convert alder/shrub communities to conifers, to release conifers from such cover, and probably to prepare sites for alder production. To thin and cull young stands of alder, trichlopyr (not yet registered), 2,4-D amine, and cacodylic acid can be effectively injected into selected trees. In conifer management, alder and associated species can be controlled with (1) 2,4,5-T before bud burst (the best release tool), and (2) brushkiller (2,4-D + 2,4,5-T) in late summer (best for release from alder, hazel, thimbleberry, cherry, and ocean spray).

To convert brushfields, the initially expensive brown-and-burn procedure is most successful. In site preparation, phenoxy's (2,4-D and 2,4,5-T) alone often require multiple treatments and often result in heavy animal use. Krenite<sup>R</sup>, picloram/phenoxy mixtures, and glyphosate (registered in Oregon only in 1977) are satisfactory if treated stems larger than 3-in diameter are felled and large seedlings, preferably less palatable species, are used." (A)

419. Newton, Michael, B. A. el Hassan, and Jaroslav Zavitkovski.  
1968. Role of red alder in western Oregon forest succession. In *Biology of alder*, p. 73-84. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- "Red alder was studied to determine influence on long-term forest succession. Juvenile growth of alder appears responsible for failure of other species, particularly conifers, to maintain positions of dominance. Success of Douglas-fir depends on delay of 4-9 years in establishment of alder, or occurrence of the two species at such spacing that Douglas-fir will be from 8 to 10 years old before encroachment by alder.
- "Alder is concentrated on mesic sites with history of scarification or fire. Dense stands were shown to fix nitrogen at an annual rate of about 320 kg per hectare on nitrogen-deficient soils. Equilibration of fixation with nitrogen in soil tends to occur before the age of 20 years, beyond which contributions of nitrogen are small.
- "Common successors to alder include salmonberry, vine maple, and hazel, in that order. Western hemlock may follow eventually, but Douglas-fir is virtually absent except where it develops concurrently with the alder in openings within the alder stand." (A)
420. Newton, William E., and C. J. Nyman, Eds.  
1976. Proceedings of the 1st international symposium on nitrogen fixation. Vol. 1. 311 p. Wash. State Univ. Press, Pullman.
421. Newton, William E., and C. J. Nyman, Eds.  
1976. Proceedings of the 1st international symposium on nitrogen fixation. Vol. 2. 313 p. Wash. State Univ. Press, Pullman.
422. Nielson, R. W.  
1977. Red alder utilization in British Columbia - present and potential. West. For. Prod. Lab. Inf. Rep. VP-X-164, 29 p. Dep. Fish. and Environ., Vancouver, B.C.
- "Red alder (*Alnus rubra* Bong.) is a common hardwood species in the Pacific Northwest, but is virtually unused in British Columbia. This booklet reviews the red alder resource situation and the extent of its utilization, with comparisons made between British Columbia and the neighboring states of Washington and Oregon.
- "Wood properties and current utilization practices are outlined, and the potential for using this species in British Columbia is discussed. Factory lumber appears to be an economically attractive product for this species, but is dependent on the consumption of mill residues and pulpwood-quality red alder by the pulping industry." (A)

423. Noble, M., J. de Temple, and P. Neergaard.  
1958. An annotated list of seed-borne diseases. 159 p. Commonw. Mycol. Inst., Kew.

"Arranged under families of the hosts, with an index to pathogens, and indexes to common and Latin names of hosts, which include Acer spp., Alnus spp. Araucaria excelsa, Betula spp., Chamaecyparis sp., Fraxinus spp., Larix spp., Picea sitchensis, Pinus spp., Quercus spp., Thuja spp., Ulmus americana and U. pumilla." (FA)

424. Norris, L. A.  
1966. Degradation of 2,4-D and 2,4,5-T in forest litter. J. For. 64(7):475-476.

"The herbicides 2,4-D and 2,4,5-T are degraded in forest litter at different rates; 2,4-D is metabolized at an increasing rate with time while the rate of degradation of 2,4,5-T shows only a slight increase. More than 895 percent of the 2,4,-D was decarboxylated in 300 hours. Less than 25 percent of 2,4,5-T was decarboxylated in the same period. Similar qualitative relationship in the persistence characteristics of these herbicides is expected in the field." (A)

425. Norris, Logan A., and David Greiner.  
1967. The degradation of 2,4,-D in forest litter. Bull. Environ. Contam. and Toxicol. 2(2):65-74.

"These studies have shown that 2,4-D is rapidly degraded in forest litter and that the rate of degradation varies with

the type of litter, herbicide formulation and the presence of DDT. The degradation of 2,4-D varies slightly in litter from different vegetation types when incubated under similar environmental conditions. Greater variation in herbicide degradation rates may be expected in the field; but this will be due primarily to differences in the site microenvironment, rather than inherent differences in the litter.

"Various formulations of 2,4-D are degraded at different rates in forest litter although we believe this to be more a function of constituents of formulation than a direct effect of the technical acid, salt or ester.

"Finally, these experiments have shown that up to 4 gallons per acre of diesel oil has little or no effect on the decomposition of 2,4-D iso octyl ester, while 1 lb./A. of DDT appears to stimulate herbicide degradation." (A)

426. Northwest Hardwood Association.  
1957. Management of red alder in the Pacific Northwest. Advisory group on forest management. 24 p. Seattle, Wash.

"Covers the silvics of Alnus rubra, thinning practices, m.a.i. and total yield, volume tables, rotations, types of felling, and logging methods. Also considers official grading rules and the judging of quality, chemical barking for pulpwood, and the relation of markets to management." (FA)

427. Northwest Hardwood Association.  
1966. Proceedings from an alder logging and milling clinic. 16 p. Seattle, Wash.

428. Nuttall, Thomas.  
1857. The North American sylva; or, a description of the forest trees of the United States, Canada, and Nova Scotia, not described in the work of F. Andrew Michaux, and containing all the forest trees discovered in the Rocky Mountains, the territory of Oregon, down to the shores of the Pacific, and into the confines of California, as well as in various parts of the United States. Vol. 1, p. 41-46. D. Rice and A. N. Hart, Philadelphia.
- "OREGON ALDER. Alnus Oregonia. Foliis lato-ovatis utrinque acutis, duplicato-serratis junioribus glutinosis, venis subtus pubescentibus pallidis; stipules oblongis deciduis glutinosis, ramulis glabris." The original description of Oregon alder now an obsolete synonym for red alder. Nuttall found it "...as usual with the plants of this genus, growing along the border of small, clear brooks near the confluence of the Wahlamet, but seldom, if ever, on the banks of the larger streams which are subject to inundation. In our progress to the West, we first observed this tree on the borders of the rivers Boisee and Brulee [Burnt River, Oregon] which pass into the Shoshonee [Snake] not far from Walla-Walla, [this area is not considered outside the range of red alder] and at intervals it continues more or less common to Point Chinhook, near the shores of the Pacific." (CFH)
429. Olson, Bob, David Hintz, and Edwin Kittila.  
1967. Thinning young stands of alder. U.S. Dep. Agric. Soil Conserv. Serv. Tech. Notes TN 122, 2 p.
- The suggested minimum spacing for young alder stands is 10-12 feet. (CFH)
430. Oregon State Department of Forestry.  
1962. Alder moves into timber management picture. For. Log 31(10):4-5.
431. Oregon State University, Cooperative Extension Service.  
1958. Oregon hardwoods, management, marketing, manufacture. Ext. Bull. 775, 16 p. Corvallis, Oreg.
432. Oregon State University, Cooperative Extension Service.  
1963. Red alder (Alnus rubra). In Woodland handbook for the Pacific Northwest, p. 167-169. Corvallis, Oreg.
- Silvicultural description of red alder. Advice and solutions to problems encountered by small woodlot owners dealing with any Northwest species. (CFH)
433. Oregon State University, Cooperative Extension Service.  
1969. Red alder (Alnus rubra). In Woodland handbook for the Pacific Northwest, p. 128-130. 2d ed. Corvallis, Oreg.
- Discusses forest management in a style and scale applicable and usable by small woodlot foresters. (CFH)

434. Oregon State University, School of Forestry.  
1961. Herbicides and their use in forestry. 122 p. Corvallis, Oreg.

"A symposium held in Corvallis on 7-9 Sept. 1961, at which 15 papers on various aspects of herbicides and their applications in forestry were presented, including: The development and characteristics of herbicides (V. H. Freed) [outlining the scope for their application in brush control in forests, and woody-weed suppression on farms, along highways, etc.]; Chemical selectivity on woody plants (J. H. Rediske); Chemical forms of phenoxy herbicides and their place in brush control (R. H. Schieferstein); Hormone herbicides (P. M. Ritty); Non-hormone types of weed and brush killers (M. C. Swingle); Herbicides in forest management in West Side (U.S.) Forests (P. G. Lauterbach); Soil herbicides in forestry (W. R. Furtick); and The legal responsibilities of herbicide use in forestry (S. W. Turner) [discussing ways in which those applying herbicides (and pesticides) may best protect themselves against the contingencies of litigation and adverse financial judgements, by insurance and by adequate assessment of the conditions under which phytotoxic materials can be used with least harm to property]." (FA)

435. Oregonian  
1975. Alder cut on Publishers Paper land. Nov. 30, p. C-2, col. 1.

436. Overholser, James L.  
1968. Oregon hardwood sawtimber. For. Res. Lab. Rep. G-9, 52 p. Oreg. State Univ., Corvallis.

"Western Oregon has extensive stands of native hardwoods of such qualities that they are suitable raw materials for making a wide selection of products. Processors and users of these woods need to know their properties so that the wood from them will provide greatest service.

"Several organizations and many individuals have published valuable information about these woods, but the numerous reports need to be combined for ready access to that information. This report is aimed at providing for that need.

"Several Oregon hardwoods supply logs for a growing industry. A dozen other species, limited in volume or without developed markets, are used little now but may be potentially valuable. Foremost in volume of lumber produced is red alder; second in production is bigleaf maple.

"Information presented here is largely about physical properties of the wood from these trees and about considerations important in their manufacture and use. Economics of the industry are not easily measured, and comments made should be taken as indications, not as definitive statements of fact." (A)

437. Pacific Northwest Forest and Range Experiment Station.  
1953. Volume tables for permanent sample plots as recommended by the Puget Sound Research Center Advisory Committee for use in western Washington. 30 p. Portland, Oreg.

"The tables comprise: (1) 'recommended' tables considered suitable for use in the area and containing data on cubic volume

for entire stem and merchantable stem, and board ft. volume by the International and Scribner rules for Pseudotsuga taxifolia, Tsuga heterophylla, Picea sitchensis, Abies amabilis, and Alnus rubra; and (2) 'interim' tables, constructed from data outside the Puget Sound area and suitable for use until improved tables are available, giving similar information for Thuja plicata, Pinus contorta var. latifolia, Populus trichocarpa and Acer macrophyllum." (FA)

438. Pacific Northwest Forest and Range Experiment Station.  
1957. Seasonal stem growth at McCleary forest. In Annual report 1956, p. 32-33. Portland, Oreg.

"Three years' records of radial increment indicated that stem growth of Red Alder, Western Red Cedar and Douglas Fir begins in the first week of May and ends in late September or early October, later for Douglas Fir than for the other two species. Increment was appreciably less in 1956 than in 1954-55, presumably because of the cold weather in Nov. 1955." (FA)

439. Pacific Northwest Forest and Range Experiment Station.  
1959. Pruning and epicormic branching in red alder. In Annual report 1958, p. 15-17. Portland, Oreg.

"Dissection of trunks of Alnus rubra pruned 20 years earlier at 21 years of age, showed that pruning scars had healed rapidly, but that development of epicormics seriously hindered the formation of clear wood. Bud strands, originating in the leaf axils, were apparently stimulated by the pruning." (FA)

440. Pacific Northwest Forest and Range Experiment Station.  
1961. Red alder and soil nitrogen. In Annual report 1960, p. 66-67. Portland, Oreg.

"Soil from under a mixed 30-year stand of Douglas Fir and Red Alder (a) was compared with that from a neighbouring pure Douglas Fir plantation of the same age, and several important differences were revealed. (1) N content of the top 12 in. of soil under (a) was 50% greater than under (b). (2) Organic-matter content in the top 6 in. was significantly greater under (a). (3) The top 36 in. of soil under (a) contained 1665 lb. more N per acre than that under (b); this represents an average annual accumulation of 64 lb./acre attributable to the Alder." (FA)

441. Pacific Northwest Forest and Range Experiment Station.  
1965. Marketing young-growth timber from Tillamook County, Oregon.  
32 p. U.S. Dep. Inter., Bur. Land Manage., Portland, Oreg.

Red alder is discussed as the principal hardwood species consumed by three mills in Tillamook County, Oregon, in 1962. (CFH)

442. Panshin, A. J., Carl de Zeeuw, and H. P. Brown.  
1964. Textbook of wood technology: Volume 1--Structure, identification, uses, and properties of the commercial woods of the United States. 2d ed. 643 p. McGraw-Hill Book Co.: New York, San Francisco, Toronto, London.
- Discusses tree growth and wood structure, the woody plant cell, the physical nature of wood, and the variability of wood within a species. Keys for the identification of commercial woods are given. Contains extensive tables on wood properties. (CFH)
443. Partridge, A. D., and F. D. Johnson.  
1964. New records of forest fungi in Idaho. Northwest Sci. 38(4):134-137.
- "Includes Poria obliqua on living Alnus rubra, a new host record for the western U.S.A." (FA)
444. Paul, B. H.  
1962. Choose the right wood. Properties and uses of some western hardwoods. Woodworking Dig. 64(3)47-49.
- "Tabulates the main sources, properties (i.e., sp. gr., modulus of rupture, hardness), and common and special uses of the following western U.S. hardwoods: Alnus rubra, Fraxinum oregonia, Populus tremuloides, P. trichocarpa, Castanopsis chrysophylla, Cornus nuttallii, Umbellularia californica, Arbutus menziesii, Acer macrophyllum, Quercus kelloggii, Q. lobata, Q. gerryana and Lithocarpus densiflorus." (FA)
445. Peace, T. R.  
1962. Pathology of trees and shrubs with special reference to Britain. 753 p. Clarendon Press, Oxford, Engl.
- The book is divided into two main parts: (1) diseases caused by nonliving and living agencies, with a breakdown into nursery diseases, root diseases, and stem, leaf, and shoot diseases; (2) descriptions of problems on important trees, groups of trees, or shrubs. Primary emphasis is on trees native to or introduced into Europe. (CFH)
446. Pechanec, Anna A., and Jerry F. Franklin.  
1968. Comparison of vegetation in adjacent alder, conifer, and mixed alder-conifer communities. II. Epiphytic, epixylic, and epilithic cryptogams. In Biology of alder, p. 85-98. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- "Epiphytic and epixylic cryptogams were compared in adjacent red alder, conifer, and mixed alder-conifer communities. Twenty-four epiphytic species were encountered. Red alder was a more favorable host than Douglas-fir or Sitka spruce in terms of number of epiphytic cryptogams and their frequency and coverage. Mosses were represented best on tree bases; liverworts, on midportions of tree trunks; and lichens, on upper trunks and in crowns. Thirteen species of epixylic cryptogams were encountered during sampling of rotten logs." (A)

447. Peters, C. C., and J. F. Lutz.  
1966. Some machining properties of two wood species grown in Hawaii--*molucca albizzia* and *nepal alder*. USDA For. Serv. Res. Note FPL-0117, 10 p. For. Prod. Lab., Madison, Wis.
- "Presents results of studies on the machining properties of Hawaiian-grown *Albizzia falcata* and *Alnus nepalensis*, showing that they are similar to those of several U.S. hardwoods (e.g., *Alnus rubra*, *Liriodendron tulipifera* etc.). If available with straight grain, the wood should be suitable for core stock." (FA)
448. Pfeiffer, J. R.  
1953. Basic data for Oregon hardwoods. Oreg. For. Prod. Lab. Rep. G-1, 40 p. Corvallis, Oreg.
449. Pfeiffer, J. R.  
1953. Western hardwoods--a promising industry. Natl. Hardwood Mag., March 27(2):43-45, 51.
450. Pfeiffer, J. R.  
1956. The case for northwest hardwoods. Pac. Coast Hardwoods, March, p. 10-11. Northwest Hardwoods Assoc., Seattle, Wash.
- "The purpose of this paper is to project into the future from information now known about Northwest hardwoods and to attempt to show why we should give more serious consideration to them, both from the standpoint of conservation of a natural resource and from the standpoint of their possible economic contribution to the region." (A)
451. Pfeiffer, J. R., and A. C. Wollin.  
1954. Red alder log and lumber grading. Oreg. For. Prod. Lab. Rep. G-3, 7 p. Oreg. State Univ., Corvallis.
- "Results of trials on 472 eight-foot logs of *Alnus rubra* showed that the log-grading rules of the U.S. Forest Products Laboratory are suitable with minor modifications, that the lumber-grading rules of the National Hardwood Lumber Association are applicable to the lumber, and that the lumber-grade recovery from logs is comparable to that from many eastern hardwoods." (FA)
452. Pfeiffer, Jack R.  
1957. General description, sources, uses, and availability of major species of Pacific coast hardwoods. Pac. Coast Hardwoods, Jan 1, p. 6-7. Northwest Hardwoods Assoc., Seattle, Wash.
- Describes wood properties of eight western hardwood species. Compares various strength properties of 18 other species with those of alder when alder properties are set at a base of 100 percent. (CFH)
453. Piper, Charles V.  
1906. Flora of the State of Washington. Volume XI of Contributions from the United States National Herbarium. 637 p. Gov. Print. Off., Washington, D.C.
- Red alder is identified as *Alnus oregona*. (CFH)

454. Piper, Charles V., and R. Kent Beattie.  
1915. Flora of the Northwest coast. 418 p. New Era Print. Co., Lancaster, Pa.

Red alder is identified as Alnus oregona.  
(CFH)

455. Plank, Marlin E.  
1971. Red alder. USDA For. Serv. Am. Woods 215, 7 p. Washington, D.C.

456. Platz, Bob J., Ed.  
1972. Washington's hardwood resources and markets. State Wash. Dep. Nat. Resour. DNR Rep. 23, 144 p. Olympia.

A collection of three discussions of the hardwoods of Washington. The western Washington resource report presents hardwood statistics as of the mid-1960's with future yield projections. Evaluations of domestic and Pacific rim export markets are covered in separate sections.  
(CFH)

457. Playfair, L., Ed.  
1956. Control of woody plants. Res. Rep. West. Sect. Natl. Weed Comm. Can. 1956:81-82.

"Monuron at 3 oz./100 sq. ft. and concentrated Borascu (89% anhydrous borax) at 9 lb./100 sq. ft. were applied to woody growth along a fence-line (chiefly Rose [Rosa sp.] and Snowberry [Symporicarpos sp.]) after the vegetation had been cut to within 3 in.

of ground level. Observations up to 18 months later showed Borascu to be much more effective on woody growth than monuron; the reverse was the case for herbaceous growth. 2,4,5-T with or without 2,4-D was applied to fence-row areas as follows: (1) 1.5 lb./acre 2,4-D plus 2 lb./acre 3,4,5-T (butoxy ethanol esters); (2) 2 lb. 2,4-D plus 1 lb. 2,4,5-T (butoxy ethanol esters); (3) 4 lb. 2,4,5-T; (4) 6 lb. 2,4,5-T. (1) and (2) were applied to an area containing Alder (Alnus spp.), Silver Poplar (Populus sp.), Blackberry (Rubus lacinatus and R. procerus) and Hawthorn (Crataegus sp.); (3) and (4) were applied to areas containing Hardhack (Spiraea sp.), Blackberry and Alder. Treatment of (1) sporadic control; (2) excellent control of all species except Hawthorn; (3) and (4) excellent control of Blackberry but very little control of Spiraea sp. 2,4,6-TBA was applied at 2 and 4 lb./acre (1) in 15 and 30 gal. water as a foliage spray and (2) in 15 gal. diesel fuel oil as a dormant overall spray. Effects were very slow to appear; after about 15 months White Poplar (Populus sp.), Ash (Fraxinum sp.), Hawthorn (Crataegus sp.), Willows (Salix sp.) and Wild Rose (Rosa sp.) were dead from treatment (1) Burr Oak (Quercus macrocarpa) developed some deformed leaves and other Quercus spp. were dying. Hazel (Corylus sp.) showed regrowth from roots; Dogwood (Cornus sp.) showed only slight effects. After 12 months, more or less similar results were showing on the same species from treatment (2)." (FA)

458. Pomeroy, K. B., and Dorothy Dixon. 1966. These are the champs. Am. For 75(2):14-35.

Largest known red alder to date is 13 feet 6 inches in circumference at breast height. It is 92 feet tall, with a spread of 54 feet. It is growing in Polk County, Oregon. (CFH)

459. Ponce, Stanley L.  
1974. The biochemical oxygen demand of finely divided logging debris in stream water. Water Resour. Res. 10(5):983-988.
- "Describes a laboratory study, using water from a typical stream in the Oregon Coast Range, to discover the effect of Pseudotsuga menziesii needles and twigs, Tsuga heterophylla needles, and Alnus rubra leaves on dissolved O<sub>2</sub> and thus on the quality of the stream water. The chemical O<sub>2</sub> demand (COD) required for total oxidation of the plant material, and the biochemical oxygen demand (BOD, i.e. the amount of O<sub>2</sub> required by micro-organisms to decompose the material) and the rate at which O<sub>2</sub> was used, were quantified over a 90-day period. The data on O<sub>2</sub> depletion obtained in the study may be of use in developing a predictive model for water quality management on forested lands." (FA)
- temperatures the BOD of A. rubra leaves after 5 days was 23.7% of their initial dry weight. The toxicity of the leachate to fish was negligible. BOD curves for each species are presented and the different reaction rates are discussed." (FA)
460. Ponce, Stanley L., and George W. Brown.  
1974. Demand for dissolved oxygen exerted by finely divided logging debris in streams. Oreg. State Univ. Sch. For. Res. Pap. 19, 10 p. Corvallis.
- "Reports a laboratory study to determine the effect of Pseudotsuga menziesii needles and twigs, Tsuga heterophylla needles and Alnus rubra leaves on dissolved oxygen and the amount of toxins in water from a forest stream. After 90 days at 20 deg C the biological oxygen demand (BOD) of P. menziesii was 115 mg/g dry weight, of T. heterophylla 164 mg/g and of A. rubra 287 mg/g. After 45 days the BOD for each species was 90% of the value of 90 days. Under fluctuating
461. Porter, Dennis R., and Harry V. Wiant, Jr.  
1965. Site index equations for tanoak, Pacific madrone, and red alder in the redwood region of Humboldt County, California. J. For. 63(4):286-287.
- "Original equations for predicting the site index for tanoak and Pacific madrone are presented. The site-index equation for red alder in Humboldt County, Calif., is very similar to one previously reported for the stands in western Washington." (A)
462. Pouques, M. L. de.  
1949. Études caryologiques sur les Fagales. I. Le genre Alnus. [Studies of cell nuclei in the Fagales. I. The genus Alnus.] Bull. du Mus. Natl. d'Hist. Nat., Paris (Ser. 2) 21, p. 147-152.
463. Preston, R. J.  
1948. North American trees.  
371 p. Iowa State Coll. Press, Ames.

464. Pulp and Paper Magazine.  
1956. New kind of wood plant in far west. Pulp and Paper 30(1):100, 101, 104.

This plant is designed to handle and process short, 8-foot alder logs between 6 and 20 inches in diameter. Bark is mechanically removed by nine debarkers before logs are chipped. (CFH)

465. Quick, Robert H.  
1957. Neutral sulfite semichemical pulping of alder. For. Prod. J. 7(7):246-247.

"Describes the method now being used by the Weyerhaeuser Timber Company for pulping Red Alder. The pulp is used for making corrugated paper." (FA)

466. Radwan, M. A.  
1969. Chemical composition of the sapwood of four tree species in relation to feeding by the black bear. For. Sci. 15(1):11-16.

"The contents of sugars, N, P, Ca, Mg, Fe, and Mn, and the kinds of sugars and soluble N compounds, in the sapwood of 20- to 30-year Pseudotsuga menziesii, Tsuga heterophylla, Thuja plicata, and Alnus rubra were determined on two areas in western Washington, one of which showed considerable, and the other little, damage to trees by Euarctos americanus.

Although on both areas there were significant differences among species in contents and kinds of some chemical constituents, total sugars and ash were the only components apparently related to feeding preferences by bears. Within species there were, however, only minor differences between the two areas. It is concluded that chemical analysis is insufficient to explain the problem of feeding by bears on the sapwood of trees." (FA)

467. Radwan, M. A., and G. L. Crouch.  
1974. Plant characteristics related to feeding preference by black-tailed deer. J. Wildl. Manage. 38(1):32-41.

"Presents data on the chemical composition and fermentability of six preferred food plants of Odocoileus hemionus columbianus, viz. Rhamnus purshiana, Vaccinium parvifolium, Pseudotsuga menziesii, Corylus californica, Alnus rubra and Acer circinatum. Differences between the species could not be related to the order of preference as food." (FA)

468. Rahmad, Abuhamed Mohamed.  
1964. A study of the movement of elements from tree crowns by natural litterfall, stem flow, and leaf wash. M.F. thesis. Coll. For. Resour., Univ. Wash., Seattle. 118 p.

469. Randall, Robert M.  
1978. Techniques and costs of converting hardwood stands to conifers. In Utilization and management of alder, p. 353-363. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The occupation by hardwoods and brush of large areas of the most highly productive coniferous timber growing sites is a vexing problem for foresters in the Douglas-fir region. In general, management of red alder is at the center of this problem. In general, management decisions have tended to favor removing hardwood-brush types and replacing them with conifer stocking.

"Considerable work has been carried out in converting hardwood-brush sites to coniferous timber types. The major portion of this work has been done on industry lands in Washington. Several conversion techniques have been employed with varying degrees of success. Techniques used include harvesting, scarification, chemical spraying, and burning. A study of the costs and successes of applying these techniques shows that, while conversion projects are expensive, they are generally financially feasible if adequate stocking is obtained the first time. It is when the conversion process must be repeated that financial feasibility is in question." (A)

470. Ray, Winfield W.  
1940. A new species of Taphrina on alder. Mycologia 32(2):155-158.

"A new species, Taphrina macrophylla, is described from leaves of Alnus rubra in California. The young leaves become

greatly enlarged, curled, and distorted, with a decided purple colour. After the ascospores are shed the leaves shrivel and fall, and a new crop of healthy leaves is produced." (FA)

471. Record, Samuel J., and Robert W. Hess.  
1943. Timbers of the New World. Use and abuse of America's natural resources. 640 p. Arno Press, New York.

The characteristics of wood by family and genus are botanically described. Important species, including red alder, are discussed further. (CFH)

472. Rediske, J. H., and George R. Staebler.  
1962. Herbicidal selectivity of chlorophenoxybutyric acids on Douglas-fir. For. Sci. 8(4):353-359.

"Pot and nursery trials of formulations of 2,4-D, 2,4-DB, 2,4,5-T, and 2,4,5-TB were followed by helicopter spraying with 2,4-DB triethyl amine and 2,4,5-TB butoxy ethanol ester, each at 4 lb. active principle/10 gal. carrier/acre, producing actual doses of 2.1-3.6 lb./acre (considered too light). Species treated were the two most responsible for excluding Douglas Fir regeneration, i.e. (a) Alnus rubra (100), and (b) Acer circinatum (94), as well as (c) Douglas Fir (0), (d) Abies grandis (60), and (e) Populus trichocarpa (9). In the aerial spraying, both salts considerably reduced the canopies of (a) and (b) without damaging the Douglas, but the 2,4,5-TB salt showed the greater selectivity, the figures in brackets being the % of crown kill achieved in the nursery tests. Its mild effects on the Poplar should be useful in weeding stands of this species." (FA)

473. Rediske, John H.  
1961. Chemical selectivity in woody plants. *Hormolog*, Ambler, Pa.  
3(2):7-9.

"Experiments were undertaken at the Weyerhaeuser Forestry Research Centre to investigate the selectivity of weed-killers. Results are tabulated, giving comparative effects of different preparations on the following species: Pinus ponderosa, Picea sitchensis, Pseudotsuga taxifolia, Tsuga heterophylla, Abies grandis, Populus trichocarpa, Alnus rubra, Salix sp., Acer macrophyllum, A. circinatum and Rubus spectabilis. (1) 2,4-D, 2,4-DB, 2,4,5-T and 2,4,5-TB triethylamine salts and butoxyethanol esters as foliage sprays: in general 2,4,5-TB gave a greater margin of differential toxicity between conifers and deciduous species (P. trichocarpa excepted) than did 2,4-DB. (2) 2,4,5-T emulsifiable acid, triethylamine and dodecylamine salts and butoxyethanol ester as foliage sprays: the dodecylamine salt had a greater effect on A. circinatum than on Douglas Fir, whereas the triethylamine salt was equally effective on both. On Sitka Spruce, however, the triethylamine salt had no toxic effect, whereas the deciduous brush species were all to some degree susceptible. (3) 2,4,5-T acid in water as foliage and dormant-season sprays: most of the conifers proved highly resistant to the dormant-season sprays, e.g. on Grand Fir they had no obvious effect, whereas growing-season sprays gave 100% kill. (4) 2,4,5-T acid in toxic or non-toxic oil as dormant-season sprays: in general, conifers sustained less damage from applications in non-toxic oil. (5) Triethylamine salts of (a) 2,4-D, (b) 2,4,-DP and (c) 2,4-DB applied in water as foliage

sprays: Douglas Fir was unaffected by (c), whereas similar concentrations of (a) and (b) gave 99% kill. On Sitka spruce, (a) had no effect, (c) gave 30% kill. On P. trichocarpa, (a) gave 100% kill and (c) only 2%. (6) Triethylamine salts of 2,4-D, MCPA and 2-chloro-4-fluorophenoxyacetic acid (2-Cl, 4-F); 2,4-D triethylamine was more toxic to Ponderosa Pine than the 2-Cl, 4-F, while for Sitka Spruce the reverse was true." (FA)

474. Rehder, Alfred.  
1911-18. *The Bradley bibliography*. A guide to the literature of the woody plants of the world, published before the beginning of the twentieth century. Compiled at the Arnold Arboretum of Harvard University under the direction of Charles Sprague Sargent. Vol. 1, 1911, 566 p.; vol. 2, 1912, 926 p.; vol 3, 1915, 806 p.; vol 4, 1914, 589 p.; vol 5, 1918, 1,008 p. Riverside Press, Cambridge.

475. Rehder, Alfred.  
1949. *Bibliography of cultivated trees and shrubs hardy in the cooler temperate regions of the northern hemisphere*. p. 101, 104. Arnold Arbor. Harvard Univ., Jamaica Plain, Mass.

"... gives references to the sources of the botanical names, valid names, and synonyms of woody plants cultivated in the cooler regions of the temperate zone of the Northern Hemisphere. ..." (A)

476. Rehder, Alfred.

1958. Manual of cultivated trees and shrubs hardy in North America exclusive of the subtropical and warmer temperature regions. 2d ed. 996 p. MacMillan Co., New York.

changing that image. Quality control and lumber sense are the key words that describe our operations goals. From expanded log consumption, constant machinery and process updating, to satisfied customers Northwest Hardwoods, Inc. has taken the Mom & Pop approach out of manufacturing alder." (A)

477. Rehill, P. S.

1968. Stimulation of Armillaria mellea rhizomorphs with alder extracts. Bi-mon. Res. Notes 24(4):34. Ottawa.

"Raabe reported that the rhizomorph production of A. mellea was stimulated by extracts from a number of wood species. Weinhold later suggested that the stimulatory substance was indole-3-acetic acid. The present paper reports stimulation by hot-water extract of Alnus rubra to a much greater degree than that obtained by IAA or ethanol." (FA)

480. Reukema, Donald L.

1965. Seasonal progress of radial growth of Douglas-fir, western redcedar, and red alder. USDA For. Serv. Res. Pap. PNW-26, 14 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Measurements of radial growth during 5 growing seasons in western Washington showed that true growth occurred between mid-April and early September with seasonal distribution of growth varying from year to year." (A)

478. Reichard, T. A.

1974. Barred owl sightings in Washington. West. Birds 5(4):138-140.

481. Rice, P. R., and D. C. Church.

1974. Taste responses of deer to browse extracts, organic acids, and odors. J. Wildl. Manage. 38(4):830-836.

"Black-tailed deer (Odocoileus hemionus) were offered a choice of water or one water extract of browse plant. Amount drunk varied according to sex and extract concentration, but there was some preference for extracts of bitterbrush (Purshia tridentata), red alder (Alnus rubra), cascara buckthorn (Rhamnus purshiana), Douglas fir (Pseudotsuga menziesii) and western hemlock (Tsuga heterophylla). Males but not females preferred solutions of malic, succinic and citric acids and, to a lesser degree, quinic acid. Smears of butyric acid and of putrefied salmon extract on the drinking vessels gave mixed responses, with sex differences." (A)

"It has been stated that the manufacture of red alder lumber is a small mill product; however, Northwest Hardwoods, Inc. has taken giant strides toward

482. Richens, R. H.  
1945. Forest tree breeding and genetics. Imp. Agric. Bur. Joint Publ. 8, 79 p. Oxford, Engl.

Summarizes literature on forest tree breeding in the period 1930-45. Separate accounts of the information pertaining to the genera of 9 gymnosperms and 22 angiosperms. Very extensive bibliography.  
(CFH)

483. Roberts, A. N., and W. M. Mellenthin.  
1959. Effects of sawdust mulches. II. Horticultural crops. Oreg. Agric. Exp. Stn. Tech. Bull. 50, 34 p. Oreg. State Univ., Corvallis.

"Summarizes experiments over an 8-year period on the effect of Douglas Fir and Alder sawdust, Oak leaves, and straw, used as mulches and soil amendments, on: yield of certain horticultural crops; incidence of red-stele disease of strawberries; and fertilizer requirements (particularly N) as measured by crop response." (FA)

484. Robinson, Dan D.  
1948. Utilization of Oregon hardwoods. Oreg. For. Prod. Lab. Inf. Circ. 2, 22 p. Corvallis, Oreg.

485. Rodriguez-Barrueco, C.  
1968. The occurrence of nitrogen-fixing root nodules on non-leguminous plants. Bot. J. Linn. Soc. 62(1):77-84.

"At present it is known that some 13 genera of non-leguminous Angiosperms include at least some species which bear root nodules with the property of

nitrogen fixation. Alnus is the best known example. To assist in the assessment of the ecological importance of these plants, the author has surveyed the relevant literature to discover how many species in each of the genera have been recorded to bear nodules. He also provides evidence of this feature in several species not hitherto reported. Of an estimated total complement of 342 species in the 13 genera, 118 species have so far been recorded to bear nodules. The remaining species do not appear to have been examined for the presence of nodules." (A)

486. Rodriguez-Barrueco, C.  
1970. [Studies on cross inoculations between N-fixing species of the genus Alnus.] An. Edafol. Agrobiol. 29(1/2):87-97.

"A suspension of triturated nodules was used for cross-inoculation of plants grown in a sterile medium. A. glutinosa (a), A. cordata (b) and A. incana (c) formed nodules rapidly after inoculation with suspensions from (a). Nodulation was slower with suspensions from A. rubra (an American species), and the inoculated plants generally showed inferior growth to those inoculated with (a). N fixation by plants inoculated with A. rubra suspensions, expressed in % of that fixed by the same species inoculated with (a) was: (a) 32, (b) 6, and (c) 19. There seems, therefore, to be a certain degree of incompatibility between the nodule-forming organisms of the American species and the European Alder, though, after a period of adaptation, the nodules thus formed were able to fix N efficiently." (FA)

487. Rodriguez-Barrueco, C., and G. Bond. 1968. Nodule endophytes in the genus Alnus. In Biology of alder, p. 185-192. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The Alnus glutinosa endophyte symbiosed satisfactorily with two other European alders (A. cordata and A. incana), but the A. rubra endophyte performed less satisfactorily on the European host species, mainly because of a delay in nodule formation. This provides further evidence that the endophytes of Alnus species from different geographical regions may not be identical. This regional specialization is particularly likely in such a widely dispersed genus as Alnus." (A)

488. Rogers, Jack D. 1968. Hypoxyton fuscum: A review of the fungus and its relationship with Alnus in the Northwest. In Biology of alder, p. 251-258. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Hypoxyton fuscum is a widely distributed inhabitant of Alnus species and other betulaceous species throughout the North Temperate Zone. The fungus causes a rapid white-type rot of wood of dead or dying Alnus plants. It probably is a weak parasite, possibly contributing to killing of trees. The morphology and development of the fungus and known aspects of its relationship to Alnus tenuifolia are discussed." (A)

489. Roof, James. 1951. Growing California's four alders. J. Calif. Hort. Soc. 12(4):167-173.

"The 4 California alders, in order of size Alnus rubra, A. rhombifolia, A. tenuifolia, and A. viridis var. sinuata, are each considered in detail, both as to their behavior in the wild and in cultivation. In full sun with abundant water throughout the year red alder 10 yrs. old may be 40 ft. in ht. and 7 in. in diam. 4 ft. above the ground. It thrives under lawn conditions. White alder, A. rhombifolia, grows in cultivation 3 ft. a yr. after the 1st 3 yrs. It may be grown under the same conditions as red alder except that it will not tolerate saline conditions. Red alder will grow in sandy soil in protected places near the sea; white alder probably will not. Fresh seed should be sown in Aug. or for white alder until Oct. Germination is 55 to 60%. Seedlings in cans should be watered almost daily and planted out after a yr. Young transplants can be moved at any time except in summer. Mountain alder, A. tenuifolia, when planted as a lawn tree, will reach a mature ht. of 16 ft. in 7 yrs. Then it will grow no higher but begins to add main trunks that grow from the base of the tree; these are not suckers or runners. Although a native of the mountains, it thrives in the bay region. The coastal form of the Sitka alder is expected to be an attractive small yard tree for the San Francisco fog belt. Germination of fresh seed of mountain alder is 48%, of coastal Sitka alder 35%. Seedlings should be held in cans for 2 yrs. Mountain alder should be watered only at the base after the 1st 3 yrs. as excessive water will turn the leaves prematurely rusty in summer. Overhead sprinkling keeps Sitka alder fresh and clean-looking. All the alders need full sun. The alders are recommended for home landscaping." (BA)

490. Ross, Herbert H.  
1932. Records of additional European sawflies in America and descriptions of new varieties of North American species. Can. Entomol. 64(11):247-251.

"The 4 following spp. are recent introductions from Europe: Hemicroca crocea Geof. (= H. washingtonia Rohw. & Middl.), on Alnus rubra, in Washington and Brit. Columbia; Selandria stramineipes Klug (= S. urbia Ross), on Pteris aquilina in Brit. Columbia; Tomostethus luteiventris, new to Brit. Columbia, on snow, 4700 ft., descr. of ♀; T. ephippium Panser (= Selandria inhabilis Norton), new to Brit. Columbia; Monosoma inferentia v. andronosa ♀ (p. 249), Ontario; Strongylogaster annulosus v. cingulercens (p. 259), Michigan (type), Ontario, New York, Illinois, and Indiana; Crabro americana v. rubrosa ♂ (p. 259), Michigan (type), Illinois, New York, S. Dakota, Manitoba, Ontario, Quebec." (BA)

491. Roy, Douglass F.  
1962. California hardwoods: Management practices and problems. J. For. 60(3):184-186.

"Briefly considers 14 species of potential commercial value, in the categories (1) stream-side, bottomland or moist-site hardwoods (Alnus rubra, in particular), (2) non-manageable hardwoods, and (3) potentially manageable hardwoods (Lithocarpus densiflorus and Quercus kelloggii)."  
(FA)

492. Rubin, A., and B. P. Beirne.  
1975. Natural enemies of the European fruit lecanum, Lecanium tiliae (Homoptera:Coccidae), in British Columbia. Can. Entomol. 107(4):337-342.

"Reports a survey of the predators and parasites of L. tiliae, based on 241 collections of infested branches and leaves of Broadleaf Maple (Acer macrophyllum), Horse Chestnut (Aesculus hippocastanum), Black Cherry (Prunus serotina), Japanese Plum, Hawthorn (Crataegus sp.) and Red Alder (Alnus rubra) on which there were 50 022 scales. Three species of parasites, 18 predators and a fungus were found. Unsuccessful attempts at biological control are briefly described." (FA)

493. Russell, Sterling A., Harold J. Evans, and Patricia Mayeux.  
1968. The effect of cobalt and certain other trace metals on the growth and vitamin B<sub>12</sub> content of Alnus rubra. In Biology of alder, p. 259-271. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"An investigation has been made of the effects of increasing concentrations of Ni, Fe, and Mn on the growth and the chlorophyll, N, vitamin B<sub>12</sub>, and Co contents of Alnus rubra in the presence and absence of 50 ppm Co in the nutrient medium. The effects of the Mn, Fe, and Ni on growth, both in the presence and absence of Co, were not statistically significant. At the first harvest (144 days after being placed in culture), the effects of the Co treatment on dry and

fresh weights of plant tops, on the chlorophyll content of leaves, and the N content of tops were highly significant. However, at the final harvest (after 213 days in culture), the plants apparently had obtained sufficient Co from contaminating sources to satisfy most of their requirements; thus, no appreciable responses to Co addition were apparent.

"The effects of the heavy metal additions on the vitamin B<sub>12</sub> content of nodules were striking and statistically significant. From the B<sub>12</sub> analyses, it appeared that increasing concentrations of Ni, Fe, or Mn resulted in marked decreases in the biosynthesis of vitamin B<sub>12</sub> in nodules. This was most pronounced where 0.05 ppm of Co was added to the nutrient solution and where the lowest increments of Ni, Fe, or Mn were added. The highest concentrations of these trace elements (Ni, Fe, and Mn) were associated with an increase in the B<sub>12</sub> content of nodules. This increase was attributed to Co impurities in Ni, Fe, and Mn salts. In general, the effects of increasing concentrations of Ni, Fe, and Mn in nutrient solutions on Co uptake by alder tissues were similar in trends to those exhibited by effects of added metals on the B<sub>12</sub> content. It is concluded that excessive Ni, Fe, and Mn may competitively interfere with the incorporation of Co into B<sub>12</sub> compounds." (A)

494. Ruth, Robert H.

1968. First-season growth of red alder seedlings under gradients in solar radiation. In Biology of alder, p. 99-105. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Red alder (Alnus rubra Bong.) seedlings were grown on mineral soil near the Oregon coast under a conifer stand thinned to provide gradients in canopy density. First-season survival was one seedling per 31 viable seeds sown, indicating a low efficiency for alder establishment compared with conifers under similar conditions. Only a small part of variation in growth was associated with radiation reaching the forest floor." (A)

495. Ruth, Robert H.

1970. Effect of shade on germination and growth of salmonberry. USDA For. Serv. Pap. PNW-96, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Thinning the forest overstory stimulated germination of viable salmonberry seed apparently present in the forest topsoil." (A)

496. Ruth, Robert H., and Carl M. Berntsen.

1956. Chemical basal treatment to control red alder. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 128, 6 p. Portland, Oreg.

"Stems of trees in a 6-year stand were sprayed with a 4 or 8% concentration of 2,4,5-T in diesel oil or 2,4,5-T plus 2,4-D to a height of 12 in. for trees <3 in. diam. and to a height equal to 4 times the diameter for larger trees. Equipment is illustrated. After 15-17 months 96% of the treated trees were dead and the remaining 4% were largely defoliated. Costs for the 8% 2,4,5-T were \$0.44/tree, and 90 trees were treated per man-hour." (FA)

497. Ruth, Robert Harvey.  
1967. Differential effect of solar radiation on seedling establishment under a forest stand. Ph. D. thesis. Oreg. State Univ., Corvallis. 176 p.

"In the main study, on the Oregon coast, scarified plots were established under a 118-year mixed conifer stand thinned to provide a range of canopy densities, and the establishment and growth of seedlings of Picea sitchensis, Tsuga heterophylla, Pseudotsuga menziesii and Alnus rubra, from natural seedfall or from sowing, were measured and related to solar radiation. The conifers all became established on mineral soil more readily than A. rubra. The intensity of solar radiation (ranging from <10 to nearly 70% of that in the open) had little effect on establishment, but growth in the first season of P. menziesii increased with radiation, and that of the other three species increased with radiation to an optimum, varying with the species from 39 to 50% of that in the open, and then declined; this decline appeared to be related to high soil moisture tension." (FA)

498. Rymer, K. W.  
1951. Red alder in British Columbia. For. Prod. Lab. Div. Bull. 98, 19 p. For. Branch, Can. Dep. Resour. and Dev., Ottawa.

"Red alder is one of the most important hardwoods in British Columbia. It is found in the coastal regions of the province and extends northward into Alaska and southward to California. It occurs in small pure stands and also in association with other hardwoods and

softwoods. The tree matures in 50 to 60 years and may reach a diameter of 20 inches. Present silvicultural experiments suggest that a growing cycle of 30 to 40 years is economically feasible.

"The wood varies in colour from pale yellow to light brown, is moderate in hardness, and moderately light in weight. It is not a strong wood and should not be used where it will be subject to severe stresses. Its chief use is for furniture manufacture, especially as core stock for overlays of valuable veneers; for "turned" parts; and, in solid form, for chairs and a variety of moderately priced furnishings. Other uses include interior panelling, fuel, charcoal, toys and novelties, paper roll plugs, fixtures, and handles. Red alder slabs and edgings are used for fuel, and some sawdust is used in smoke-curing meat and fish.

"Investigations indicate that under managed growth conditions, where a reliable source of supply could be assured, the uses of alder might be extended to include products of both the plywood and pulp industries." (A)

499. Sakai, A., and C. J. Weiser.  
1973. Freezing resistance of trees in North America with reference to tree regions. Ecology 54(1):118-126.

"Dormant one-year-old twigs of about 70 tree species were collected during mid-winter from five tree regions in North America (Rocky and Western Mountain, Northern, Pacific Coast, Southeastern Coast, and Central and Eastern Lowlands). The twigs were artificially hardened in a regime of sub-freezing temperatures between -3° C and -10° C for 24 days to induce maximum freezing resistance.

"Four Northern species, Populus tremuloides, Populus balsamifera, Betula papyrifera and Larix laricina had the greatest freezing resistance of the species tested. They resisted freezing to -80° C and even immersion in liquid nitrogen (-196° C) following prefreezing to -15° C. Most of the Northern and Rocky and Western Mountain conifers survived freezing between -60° and -80° C while several species from the Pacific and Southeastern Coast regions, which have relatively mild humid winter climates, were hardy to only about -15° C.

"The ranges of some Pacific Coast species such as Pseudotsuga menziesii, Thuja plicata and Tsuga heterophylla extend into the mountainous inland. Samples collected from inland sites were found to be much hardier than those from the coast. A similar trend was observed in the various collections of Tsuga heterophylla from northern, central, and southern areas along the Pacific Coast.

"Winter minimal temperatures are among the important factors setting the northern boundaries of the natural ranges of many forest tree species. However, Populus deltoides and Salix nigra from locations with temperate or moderate winter climates survived freezing to at least -50° C irrespective of their native habitats. In these species, winter minimal temperatures do not appear to be the principal factor governing geographic distribution." (A)

500. Sander, G. H.  
1958. Oregon hardwoods:  
Management, marketing, manufacture.  
Oreg. State Univ. Fed. Coop. Ext.  
Bull. 775, 16 p. Corvallis.

501. Sargent, Charles Sprague.  
1890. The silva of North America--  
a description of the trees which  
grow naturally in North America  
exclusive of Mexico. Vol. 9,  
p. 73-74. Reprinted in 1947. Peter  
Smith, New York.

Classical botanical description of red  
alder under the name Oregon alder, Alnus  
oregona Nuttall. (CFH)

502. Sawbridge, D. F., and M. A. M. Bell.  
1972. Vegetation and soils of shell  
middens on the coast of British  
Columbia. Ecology 53(5):840-849.

"Twenty three archaeological midden sites  
were studied. Alnus, Thuja, Tsuga, and  
Pseudotsuga dominant vegetation types  
were distinguished. Midden soil profiles  
are described and their physical and  
chemical properties tabulated. The  
midden deposits, which were overlain by  
an organic horizon and, at some sites,  
mineral horizons, were composed primarily  
of shell and some ash in black soil.  
Radiocarbon dating of shell samples  
indicated ages from 770 to 6250 years  
B.P. Negative relationships were found  
between age and exchangeable Ca, Total N  
and organic C." (SO)

503. Schmitz, John.  
1976. Alder: From a "weed" to a  
valuable species. Crow's For.  
Prod. Dig. 54(3):26-27.

A brief history of red alder promotion  
as a hardwood species. Lists several  
manufacturers using alder and their  
products. Red alder is promoted under  
the trade name western alder. (CFH)

504. Schniewind, A. P.  
1966. Irregularities of finished surfaces caused by unequal ray shrinkage. *For. Prod. J.* 16(8):66-67.

"'Grain raising' in table tops of Alnus rubra was found to be related to the low radial shrinkage of ray tissue. Only a very narrow range of fluctuation in m.c. ( $< \pm 3\%$ ) could be tolerated without giving rise to noticeable effects." (FA)

505. Schopmeyer, C. S.  
1974. Alnus B. Ehrh. Alder. In Seeds of woody plants in the United States, p. 206-211. C. S. Schopmeyer, Tech. Coor. U.S. Dep. Agric. Agric. Handb. 450. Washington, D.C.

Information and data on the seed of alder species growing in the United States. (CFH)

506. Schroeder, Herbert A., and Edward D. Hansen.  
1968. Two-stage high-yield sulfite pulping of red alder. *Tappi* 51(1):1-7.

"Within arbitrarily set limits, two-stage pulping conditions were determined, which produced a high-yield pulp from red alder having the best overall strength properties. Those cooks, consisting of a bisulfite first stage and a slightly alkaline second stage, produced pulps with the highest strength characteristics. These pulps were chemically characterized, with particular attention given the xylan constituent, which was isolated and further analyzed. The major hemicellulose, O-acetyl-(4-O-methylglucurono)-xylan, had most of the

acetyl groups removed and the reducing end groups partially oxidized, but the uronic acid groups were completely retained during the pulping process. The cellulose appeared to be retained almost quantitatively and together with a relatively high hemicellulose content, gave a high-yield pulp with desirable properties. The good retention of the carbohydrate material by the pulp can probably be ascribed to the oxidative effect of the first-stage bisulfite liquor, which resulted in protection against alkaline degradation in the second stage of the pulping process. This oxidative protection was shown by the identification of xylonic acid as one of the more important acidic end groups of the xylan retained in the pulp." (A)

507. Schubert, Karel R., and Harold J. Evans.  
1976. Hydrogen evolution: A major factor affecting the efficiency of nitrogen fixation in nodulated symbionts. *Natl. Acad. Sci. USA Proc.* 73(4):1207-1211.

"Nitrogenase-dependent hydrogen evolution from detached legume nodules and from reaction mixtures containing cell-free nitrogenase has been well established, but the overall effect of hydrogen evolution on the efficiency of nitrogen fixation *in vivo* has not been critically assessed. This paper describes a survey which revealed that hydrogen evolution is a general phenomenon associated with nitrogen fixation by many nodulated nitrogen-fixing symbionts. An evaluation of the magnitude of energy loss in terms of the efficiency of electron transfer to nitrogen, via nitrogenase, in excised nodules suggested that hydrogen production may severely reduce nitrogen fixation in many legumes where photosynthate supply is a factor limiting

fixation. With most symbionts, including soybeans, only 40-60% of the electron flow to nitrogenase was transferred to nitrogen. The remainder was lost through hydrogen evolution. In situ measurements of hydrogen evolution and acetylene reduction by nodulated soybeans confirmed the results obtained with excised nodules. In an atmosphere of air, a major portion of the total electron flux available for the reduction of atmospheric nitrogen by either excised nodules or intact nodulated plants was utilized in the production of hydrogen gas. Some nonleguminous symbionts, such as Alnus rubra, and a few legumes (i.e., Vigna sinensis) apparently have evolved mechanisms of minimizing net hydrogen production, thus increasing their efficiency of electron transfer to nitrogen. Our results indicate that the extent of hydrogen evolution during nitrogen reduction is a major factor affecting the efficiency of nitrogen fixation by many agronomically important legumes." (BA)

508. Schumann, D. R.

1972. Dimension yields from alder (Alnus rubra) lumber. USDA For. Serv. Res. Pap. FPL-170, 12 p. For. Prod. Lab., Madison, Wis.

"Presents charts for determining yields of dimension stock from the top three grades of A. rubra lumber, and explains their use in yield and cost comparisons to indicate the most economical choice of grade or combination of grades for a specific cutting order." (FA)

509. Schwartz, Sidney L.

1958. Hardboard from red alder and from a mixture of slow-growth southern oaks. U.S. For. Prod. Lab. Rep. 2125, 8 p. Madison, Wis.

"A study (1) to demonstrate the suitability of two widely different classes of hardwood (Red Alder [Alnus rubra] and a mixture of Red and White Oaks [Quercus falcata, Q. coccinea, Q. velutina, Q. stellata, Q. alba and Q. prinus]) for the production of hardboard, and (2) to discover how the degree of hydrolysis influences yield, board strength, and sizing efficiency. The following factors were covered: the effect (i) of the degree of steam cooking on yield and quality of the board stock, (ii) of the amount of alum and of size added to the stock on board quality, and (iii) of pressure on Oak hardboard. From the data obtained on the response of both materials to defibration, pulping and pressing treatments, it was established that for untreated hardboard prepared from both classes, (a) the flexural strength and toughness reach an optimum at the 83-85% yield level; (b) water absorption and thickness and volume-change decrease with yield; and (c) the linear dimensional change, though relatively small, increases with a decrease in yield. As Oak was sensitive to steam cooking it was necessary to defibrate it at 125, and the Alder at 175 lb./sq. in." (FA)

510. Sedell, James R., Frank J. Triska, and Nancy M. Triska.  
1975. The processing of conifer and hardwood leaves in two coniferous forest streams: I. Weight loss and associated invertebrates. *Verh. Int. Ver. Limnol.* 19(3):1617-1627.

Douglas-fir and bigleaf maple leaves decomposed slower than red alder or vine maple leaves in two streams in western Oregon. The differences in breakdown rates between the streams may be explained by the differences in the number of invertebrate colonizers on the leaves. Differences between species are believed to be related to the rate at which they are conditioned by microbes. (CFH)

511. Shaw, Charles Gardner.  
1958. Host fungus index for the Pacific Northwest. I. Hosts. *Wash. Agric. Exp. Stn. Circ.* 335, 127 p. Pullman.

512. Shaw, Charles Gardner.  
1958. Host fungus index for the Pacific Northwest. II. Fungi. *Wash. Agric. Exp. Stn. Circ.* 336, 237 p. Pullman.

513. Shaw, Charles Gardner.  
1973. Host fungus index for the Pacific Northwest. I. Hosts. *Wash. Agric. Exp. Stn. Bull.* 765, 121 p. Pullman.

Records known occurrences and distributions of parasitic fungi in the Pacific Northwest. Volume I lists host species of vascular plants except Gramineae. Alnus rubra is reported to be attacked by 167 species of fungi. Citations to attacking species are not given but can be supplied by Washington State University on request. (CFH)

514. Shaw, Charles Gardner.  
1973. Host fungus index for the Pacific Northwest. II. Fungi. *Wash. Agric. Exp. Stn. Bull.* 766, 162 p. Pullman.

Lists by species fungi parasitizing vascular plants in the Pacific Northwest and provides a cross index to the host species listed in volume I (513). At least one literature reference to each fungus genus is included. (CFH)

515. Shelford, J. A., W. D. Kitts, and C. R. Krishnamurti.  
1970. Utilization of alder sawdust (Alnus rubra) by ruminants. *Can. J. Anim. Sci.* 50(1):208-209.

Feeding on sawdust of red alder by cattle was associated with a change in the volatile fatty acid composition of rumen fluids. These changes indicate extensive fermentation of the sawdust by rumen microflora and suggest that sawdust be used as a source of food and energy for the cattle. (CFH)

516. Sheth, K., E. Bianchi, R. Wiedhopf, and J. R. Cole.  
1973. Antitumor agents from Alnus oregona (Betulaceae). *J. Pharm. Sci.* 62(1):139-140.

"The chloroform extract of Alnus oregona showed antitumor activity against the Walker 256 (5WA16) tumor system. Lupeol and betulin were identified as the two constituents responsible for this activity." (BA)

517. Silver, W. S.

1969. Biology and ecology of nitrogen fixation by symbiotic associations of non-leguminous plants. Royal Soc. London Proc. (Ser. B) 172(1029):389-400.

"A literature review, with discussion on cytological aspects of nodulation in, and the ecological role of, such nodule-bearing genera as Alnus, Casuarina, Ceanothus, Coriaria, Myrica and Podocarpus." (FA)

518. Silvester, W. B.

1976. Ecological and economic significance of the non-legume symbioses. In Proceedings of the 1st international symposium on nitrogen fixation, Vol. 2, p. 489-506. William E. Newton and C. J. Nyman, eds. Wash. State Univ. Press, Pullman.

All the nonlegume root nodule plants are woody perennial shrubs or small trees. As such, they find little direct use and are not readily adaptable to agricultural use as direct or indirect sources of combined nitrogen. The only really significant contribution is that of red alder. (CFH)

519. Sivak, Bela, and C. O. Person. 1973. The bacterial and fungal flora of the bark, wood, and pith of alder, black cottonwood, maple, and willow. Can. J. Bot. 51(10):1985-1988.

"The occurrence and distribution of symbiotic cauloplane organisms on dormant cuttings of 1- to 2-year-old stems of alder, black cottonwood, maple, and willow were determined from tissue samples removed to 2% malt extract and nutrient broth agars, and from scanning electron micrographs of the bark surface. Fungal and bacterial symbionts were found to be confined to the bark surfaces, where their occurrence was related to the surface topography. Inner bark, wood, and pith were virtually aseptic." (A)

520. Skinner, Edgel C.

1959. Cubic volume tables for red alder and Sitka spruce. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 170, 4 p. Portland, Oreg.

"Three tables supplementing or amending those already published." (FA)

521. Smith, Harvey H.

1956. Improved utilization of western hardwoods by modern drying. For. Prod. J. 6(3):121-124.

"Describes uses and resources (estimated at 23,000 million bd. ft. for the more important species) and discusses both air and kiln drying. Species mentioned are Alnus rubra, Acer macrophyllum, Fraxinus latifolia, Populus trichocarpa, Lithocarpus densiflorus, Umbellularia californica and Quercus kelloggii." (FA)

522. Smith, J. H. G., and D. S. DeBell. 1973. Opportunities for short rotation culture and complete utilization of seven northwestern tree species. *For. Chron.* 49(1):31-34.

"Presents new data for the average height and d.b.h. of well spaced trees of Alnus rubra, Pinus contorta, Populus tremuloides, P. trichocarpa, Pseudotsuga menziesii, Thuja plicata and Tsuga heterophylla in fully stocked young stands (5, 10, and 15 years old) on good sites in southern British Columbia. Data on the above-ground weight distribution of tree components, the green sp. gr. of wood and bark, and the estimation of tree volume are compiled from various sources. Other new data indicate that very high yields of small stemwood (for fibre products) can be obtained on short rotations (8 and 2 years respectively) with dense stands of A. rubra and coppice stands of P. trichocarpa. Some practical problems of this type of management are discussed." (FA)

523. Smith, J. H. G., and D. S. DeBell. 1974. Some effects of stand density on biomass of red alder. *Can. J. For. Res.* 4(3):335-340.

"Stand density (degree of crowding of trees within stocked areas) was studied in relation to formation and yield of juvenile red alder (Alnus rubra Bong.) stands. Large variations in tree size and biomass of fully-stocked stands were associated with differences in stand density. Measurement of density in addition to stocking (the fraction of area occupied by trees) will improve biomass studies. It will also facilitate comparisons of biomass results with existing information from spacing studies and yield tables." (A)

524. Smith, J. H. G., and J. W. Ker. 1957. Timber volume depends on  $D^2H$ . *B.C. Lumberman* 41(9):28, 30.

"The values of the constants a and b within given limits of d.b.h. (D) or of the last term, are tabulated for  $V = a + b \frac{D^2H}{100}$ , where V is volume and H is total height. Species (grouped variously for maturity, d.b.h., and provenance) include Douglas and Balsam Fir, Thuja plicata and Chamaecyparis nootkatensis, Tsuga heterophylla, Sitka and 'interior' Spruce (Picea spp.), Pinus monticola, P. ponderosa and P. contorta, Larix occidentalis, Alder, Birch, Maple, Cottonwood and Aspen, in British Columbia. Another table shows the standard error in % for very tall and very short trees for each species or group." (FA)

525. Smith, J. H. G., and A. Kozak. 1967. Thickness and percentage of bark of the commercial trees of British Columbia. 33 p. Fac. For., Univ. B.C., Vancouver.

"Thickness and percentage of bark at stump, breast height and tenths of total height above breast height were analysed in relation to tree and section characteristics for mature trees in 19 species or species groups. Dbh and bark thickness at breast height are the best indicators of tree bark thickness. Dob at that height is the best indicator of bark thickness at any particular height in a tree. Influences of age, crown class, various crown characteristics, and sapwood thickness also are statistically significant but of lesser importance.

"Data on young trees which have thinner bark than mature trees were summarized for Douglas fir, western hemlock, western red cedar, silver fir, black cottonwood, and red alder. For a given dbh, root thickness is less than at the root collar; but similar diameters of root collar, bole, and branch have just about the same thickness of bark." (A)

526. Smith, J. H. G., and A. Kozak.  
1971. Thickness, moisture content, and specific gravity of inner and outer bark of some Pacific Northwest trees. *For. Prod. J.* 21(2):38-40.

"Improved methods involving bark thickness and percentages and corrections for volumes lost in voids are discussed. Tabulated averages and measures of variation in thickness, moisture, and specific gravity provide new data about both inner and outer bark for 19 common tree species of the Pacific Northwest, 13 conifers, and six hardwoods." (A)

527. Smith, J. Harry G.  
1957. Forest history from aerial photographs. *For. Chron.* 33(4):390-392.

"A brief comparison of two series of aerial photographs of a research forest, taken in 1949 and 1955 respectively, illustrating the kind of information to be obtained from such a scrutiny on e.g. the pattern of reproduction, weeds etc." (FA)

528. Smith, J. Harry G.  
1964. Root spread can be estimated from crown width of Douglas fir, lodgepole pine, and other British Columbia tree species. *For. Chron.* 40(4):456-473.

"Root systems of trees blown down by a gale in October 1962 in the U.B.C. Campus forest were excavated and studied. Roots of 90 Douglas Fir, 81 Western Hemlock, 61 Western Red Cedar, and 33 Red Alder trees were mapped and analysed in relation to 18 tree and stand variables. Average and maximum radius of roots of Douglas Fir and Lodgepole Pine were also analysed in relation to crown width, d.b.h., height, age, and other tree and stand characteristics. Ratios of root spread to crown width were influenced by species, stand density, and soil type. Ratios averaged 1.1 for open- and 0.9 for forest-grown Douglas Fir, but were 2.4 for both open- and forest-grown Lodgepole Pine on peat or poorly drained soils." (FA)

529. Smith, J. Harry G.  
1968. Growth and yield of red alder in British Columbia. In *Biology of alder*, p. 273-286. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"A gross volume of 1 billion cubic feet of red alder exists on about 350,000 acres of British Columbia forest land that could produce much higher values if stocked with Douglas-fir or black cottonwood. However, the characteristically rapid juvenile growth of alder from seed, which permits full stocking at

early ages, may prove valuable for management of alder on very short rotations. Data are presented on radial growth and important tree characteristics for open- and forest-grown trees.

Regressions of crown width on dbh and a yield table based on these are included. It is shown that crown width and root spread are highly correlated. Several total cubic-foot tree volume equations are given, and it is noted that one of these,  $V/B = 0.44H$ , also can be used to estimate growth and yield per acre.

Merchantable volume factors and reductions for decay, waste, and breakage are summarized. Distributions of section volumes and diameters inside bark are described by regression equations. Data on bark thickness and percentage are summarized. British Columbia Forest Service normal yield and stand tables for alder and Schon's empirical merchantable yield table, as well as data from University of British Columbia campus and Haney Forests, are used to illustrate the need for early and effective control of spacing." (A)

530. Smith, J. Harry G.

1972. Tree size and yields in juvenile red alder stands.  
Northwest Sci. Assoc. Annu. Meet.  
1972, 35 p. Bellingham, Wash.

"Interest in biomass analysis and incomplete stand utilization has focussed attention on species such as red alder, Alnus rubra Bong. that are prolific seeders and abundant on disturbed sites. Information collected since 1967 by a variety of methods has been analysed to describe growth of stands up to 10 years of age. Moisture contents, specific gravity, and fresh and dry-weight

components have been determined on 131 young trees. Size, volume, bark characteristics, form, taper, and other elements of growth and yield have been studied on 457 trees including some sprout clumps which have originated following cleaning. Yields measured on small plots and those calculated directly from crown area and other variables indicate potential values from short-rotation management." (A)

531. Smith, J. Harry G.

1974. Biomass of some young red alder stands. Proc. Int. Union For. Res. Organ. Meet., Vancouver Biomass Studies, Coll. Life Sci. and Agric., Univ. Maine, Orono, p. 401-410.

"Moisture contents, specific gravity, and fresh- and dry-weight components have been measured on 131 young red alder trees (Alnus rubra Bong.). Size, volume, bark, form, and taper of 457 red alder trees from 1 to 10 years in age have been analysed intensively by graphical and multiple regression methods. Yields have been determined in a variety of stand conditions ranging from isolated open-grown trees to the densest thickets that could be found as a result of natural seeding on bare ground. Yields from very young stands have been compared with those found in young and mature types on the South Coast of British Columbia. Growth in dense stands has been evaluated on 19 small plots for two years. Biological and managerial implications of both average and maximum yields in biomass and volume are discussed, briefly." (A)

532. Smith, J. Harry G.

1978. Growth and yield of red alder: Effects of spacing and thinning. In Utilization and management of alder, p. 245-263. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"In this paper I review information on the growth and yield of red alder. Recent point sample studies of 131 trees from Point Grey near Vancouver, British Columbia and 116 trees from the University of British Columbia Research Forest near Haney, B.C. are reported to show how trees and stands grow. Most attention is paid to the few studies which have demonstrated how growth of 20-year and older stands can be concentrated on fewer, higher quality stems.

"Because very little is known about potential gains from spacing, planting, or precommercial thinning of red alder in the Pacific Northwest, I summarize data from current studies. Tree ring analyses of disks and cores are used to learn how surviving trees in old stands grew when young. I also discuss problems caused by multiple, missing, and locally absent rings. The critical period of stand establishment and heavy self-thinning is described using data from eight 0.1-acre plots in 8- to 10-year-old stands and from two 0.1-acre plots in 25-year-old stands. The basic units were 0.001-acre plots in which species and d.b.h. of all live and dead trees were recorded. Comparisons are made

between several characteristics of mean trees on 0.001-acre plots and the biggest trees on 0.01 acres (top height trees). The 0.001-acre plots are regrouped into various plot sizes and configurations and stand densities measured by numbers of trees, d.b.h., and basal area to show what increases in d.b.h. and height might result from spacing and thinning. I summarize stand density indices and stocking as expressed by crown cover as well as discuss the roles of light-seeking and lean in self-thinning. I give examples of the numbers of years required to grow to breast height and patterns of growth in height and diameter by deciles above breast height and I compare recent annual height growth with growth of branches.

"Premiums for size and quality for well-spaced stands are reviewed in comparison with gains in volume for very dense stands. I conclude that stand managers have many exciting options for improving growth and yield of red alder; but, in order to confirm conclusions drawn tentatively from examination of temporary plots, sustained studies of spacing and precommercial thinning are needed." (A)

533. Smith, J. Harry G., and Robert E. Breadon.

1964. Combined variable equations and volume-basal area ratios for total cubic foot volumes of the commercial trees of B.C. For. Chron. 40(2):258-261.

"Presents revised tables for B.C. and discusses their practical application." (FA)

534. Smith, J. Harry G., and Donald D. Munro.

1965. Point sampling and merchantable volume factors for the commercial trees of British Columbia. Univ. B.C., Fac. For., 39 p. Vancouver, B.C.

"Point-sampling factors (PSF) are stated as volume per square foot of basal area at breast height. They have been calculated here in both cubic and board feet (B.C. Log Rules) for the commercial trees of British Columbia. PSF have been derived from standard volume tables and taper curves prepared by the B.C. Forest Service and have been checked against data from other tables and from samples collected in the field. PSF can be used directly to simplify summary of data collected with the aid of a prism or relascope.

"Merchantable-volume factors (MVF) are stated as ratios of total cubic foot volumes that remain after deductions have been made for standard of utilization expected and for amounts of loss anticipated from decay, waste, and breakage. In addition some approaches to theoretical derivation of MVF are described to provide checks on empirically derived constants.

"PSF and MVF are tabulated to facilitate their use in field or office. Factors that govern tree volume, methods of measuring tree volume, and tests of the various approaches to calculation of PSF and MVF are described briefly." (A)

535. Smith, Nicholas J.

1978. Red alder as a potential source of energy. In Utilization and management of alder, p. 139-155. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The energy plantation is defined and set in the Pacific Northwest energy context. Analyses on naturally established 8- to 10-year-old red alder (Alnus rubra Bong.) at University of British Columbia are used to demonstrate above-ground yields and energy flows. Results show a current net community productivity of 28.5 oven dry metric tonnes/ha per yr (conversion efficiencies of 3-percent visible net radiation), and a mean annual productivity of 9.0 oven dry metric tonnes/ha per yr. Possible sources of fuel by bioconversion are discussed. Fluidized-bed, combined-cycle systems have good prospects for electrical generation. To satisfy British Columbia's (B.C.) 1981 energy needs, at least  $1.2 \times 10^7$  ha of alder plantations will be needed (12 percent of B.C.). Use will probably continue as domestic fuelwood. A market for supplements to utilities based on coal, mill waste, and forest waste may develop. In the long-term, small energy plantations for local communities in B.C. are envisaged. The term biomass farm is used preferentially since it allows flexible appropriation of yields to a spectrum of potential uses." (A)

536. Smith, R. S., and C. V. Sharman.

1971. Effect of gamma radiation, wet-heat, and ethylene oxide sterilization of wood on its subsequent decay by four wood-destroying fungi. Wood & Fiber 2(4):356-362.

"Sapwood of Alnus rubra and Pinus ponderosa was sterilized by impregnation with ethylene oxide, steaming at 121° C or -radiation at three dosages ( $2.5 \times 10^6$ ,  $5.0 \times 10^6$ , and  $10^7$  rad), and then exposed to two brown-rot and two white-rot fungi. Gamma radiation at  $2.5 \times 10^6$  rad is a suitable alternative to the other methods of sterilization.

A small loss of wood occurs at all three radiation doses. A dosage of  $10^7$  rad caused a significant increase in decay of both wood species by Poria weiri." (FA)

537. Springer, E. L., F. L. Schmidt, W. C. Feist, L. L. Zoch, Jr., and G. J. Hajny.

1975. Storage of red alder chips with and without bark - treated and untreated. USDA For. Serv. Res. Pap. FPL-261, 9 p. For. Prod. Lab., Madison, Wis.

"Screened chips from unbarked and barked Alnus rubra logs were stored for 6 months in simulators of chip piles. Large losses in wood substances, pulp yield and pulp strength occurred in both types of chips equally; slightly more heat was evolved in barked chips during the last 4 months of storage. Immersion of the chips in 0.1% metham-Na + 0.4% Na 2,4-dinitrophenol before storage was effective in preventing losses." (FA)

538. Springer, Edward L., Fred L. Schmidt,

William C. Feist, Lawrence L. Zoch, Jr., and George J. Hajny.

1975. Recent results in chip storage - comparisons of the storage characteristics of chips produced from barked and unbarked red alder logs. Tappi Annu. Meet. 1975:83-91.

"Chips produced from unbarked (rough) and debarked red alder logs were stored for 6 months in chip pile simulators. Only minor differences were found in the storage characteristics of the untreated chips. During the last 4 months of storage, a little more heat was evolved from the bark-free chips. Large losses in wood substance, pulp yield, and pulp

strength were observed; however, they were essentially the same for both types of chips. Treatment of both types of chips by immersion in an aqueous solution of sodium N-methyldithiocarbamate + sodium, 2,4-dinitrophenol very effectively preserved the chips." (A)

539. Staebler, George R.

1960. Basal injection of 2,4,5-T fails to kill red alder and bigleaf maple. For. Res. Note 23, 2 p. Weyerhaeuser Co., Centralia, Wash.

"Trees of 4-26 in. diam. at ground line in S.W. Washington were mostly unharmed by 2,4,5-T in diesel oil, injected with the Little tree injector in incisions 2, 5 and 8 in. apart. Failure to kill was presumably due to failure to get enough chemical into the stem. Trees were successfully killed with a similar chemical squirted into frill girdles." (FA)

540. Stark, Eric W.

1953. Wood anatomy of the Betulaceae indigenous to the United States. Agric. Exp. Stn., Stn. Bull. 602, 31 p. Purdue Univ., Lafayette, Ind.

"Includes keys to photomicrographs for the identification of seven species of Betula, six of Alnus, one of Carpinus, three of Ostrya, and two of Corylus." (FA)

541. Starker, T. J.  
1939. A new alder. J. For.  
37(5):415-417.
- Describes Alnus rubra var. pinnatisecta as a new cut-leaved variety of red alder. (CFH)

542. Steele, Robert W.  
1971. Red alder habitats in Clearwater County, Idaho. M.S. thesis. Univ. Idaho, Moscow. 88 p.

"Seral stands of Alnus rubra grow in northern Idaho disjunct from populations west of the Cascade Range. A study of red alder habitats along the north Fork of the Clearwater River revealed other coastal disjunct and endemic species uncommon in the northern Rocky Mountains. Climax stands of Thuja plicata and Tsuga heterophylla in red alder habitat had undescribed understories dominated by ferns. A Dryopteria austriaca - D. filix-mas union and an Adiantum pedatum union were described as new habitat types. Association tables show that certain species appear confined to these two unions while other species common to the Pachistima union appear excluded. Red alder habitats support several species unreported from Clearwater County including Viola sempervirens, a disjunct species unreported from Idaho. Certain other species on or near red alder habitats have consistently aberrant morphological and ecological traits which suggest an inclination of these plants to resemble related taxa growing west of the Cascades."

"Stands of red alder had under-stories similar to those in adjacent climax communities. Site indices for red alder ranged from 71 to 104 but averaged only slightly lower than those west of the Cascades." (A)

543. Stenzel, George.  
1954. Marketing woodlot products in the State of Washington. Inst. For. Prod. Bull. 15, 56 p. Univ. Wash., Seattle.

Assorted information on wood specifications, potential markets, log scale, and standing volume tables for Pacific Northwest tree species, including red alder. Useful for the small woodlot owner. (CFH)

544. Stettler, R. F., and J. C. Cummings.  
1973. A guide to forest-tree collections of known source or parentage in the Western United States and Canada. Results of a preliminary survey. Coniferous For. Biome Bull. 3, 59 p. Coll. For. Resour., Univ. Wash., Seattle.

"This publication reports the results of a preliminary survey listing 527 forest-tree plantations in the western United States and Canada. Of these, 250 involve families of known parentage, 131 provenance-test material, 87 clonal material, and 59 interspecific hybrids. The report is intended (1) to serve forest researchers in locating genetic material relevant to their work, and (2) to facilitate an assessment of regional forest-gene resources. A list of agencies, a species index, a brief discussion of survey results, and recommendations complete the report." (A)

545. Stettler, Reinhard F.  
1978. Biological aspects of red alder pertinent to potential breeding programs. In Utilization and management of alder, p. 209-222. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"After a brief introduction to general concepts of genetic improvement, I discuss selected biological factors of red alder (Alnus rubra) affecting the feasibility and direction of potential breeding programs. These factors include the diversity of the genus, the species' life history, growth, reproductive biology, and nitrogen fixation. Because of its early sexual maturity, annual seed crops, and rapid juvenile growth, red alder promises to offer comparatively large genetic gains per unit of time and effort. Three alternative improvement programs with different emphases appear meritorious, i.e., (1) short- rotation fiber production, (2) normal-rotation log production, and (3) nitrogen production. Pending genetic improvement, information is needed on basic genetic parameters and on silvicultural techniques of intensive management." (A)

546. Steucek, G. L., and R. M. Kellogg.  
1975. Action potentials in Alnus rubra stem segments in relation to mechanical stress. (Abstr.) Pa. Acad. Sci. Proc. 49(1):93.

"After a 30 second period of mechanical stress, action potentials were recorded from alder (Alnus rubra) stem segments using Ag:AgCl electrodes. Subsequently, electrical stimulation was employed to

elicit and characterize these action potentials. Action potentials had a stimulation threshold, a refractory period which illustrated fatigue, and a rest time characteristic of plant cells. These action potentials could not be produced in tissue killed by heat or treated with dinitrophenol. Only when tissue was hyperpolarized did action potentials occur. The ability of stem tissue to generate action potentials varied with the season." (A)

547. Stewart, R. E.  
1972. Field screening of granular herbicides on pole-size red alder. West. Soc. Weed Sci. Res. Prog. Rep., p. 19-20.

"In evaluation of granular herbicides for the control of woody and herbaceous weeds in Alnus rubra communities in coastal Oregon and Washington, dicamba at 15 lb/acre and picloram at 5 lb/acre gave complete top kill of Sambucus callicarpa and S. glaucus, while Rubus vitifolius was best controlled with picloram at 15 lb. Picea sitchensis saplings were killed by picloram at 0.5 lb/acre and by dicamba at 5 and 15 lb/acre but proved resistant to karbutilate. Herbaceous ground cover was reduced by ca. 70% with 15 lb/acre of any of the herbicides. March and April appeared to be the best months for application." (FA)

548. Stewart, R. E.

1972. Field screening of stem applied herbicides on Coast Range brush species. West. Soc. Weed Sci. Res. Prog. Rep., p. 18-19.

"In trials in Oregon and Washington, stems of Acer circinatum, Alnus rubra, Corylus cornuta, Rubus spectabilis, and R. parviflorus were sprayed thoroughly at bud-break with 2,4-D, 2,4,5-T, dichlorprop, Silvex (fenoprop) and dicamba, alone or in mixtures, at 1 lb/100 gal diesel oil. By the end of the first growing season, 2,4,5-T and fenoprop resulted in the best defoliation and top-kill, while the incidence of re-sprouting on plots treated with 2,4,5-T was reduced by the addition of dicamba. All treatments suppressed re-sprouting of Alnus rubra." (FA)

549. Stewart, R. E.

1974. Budbreak sprays for site preparation and release from six coastal brush species. USDA For. Serv. Res. Pap. PNW-176, 20, p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Ten herbicides or combinations of herbicides were applied at budbreak on red alder, salmonberry, western thimble berry, vine maple, California hazel, and salal. Results show that red alder, vine maple, and California hazel can be adequately controlled for conifer release by budbreak sprays of 2,4,5-T applied in diesel oil. Sprays containing 2,4,5-T are promising for control of salal, but additional tests are necessary. Budbreak sprays should

not be used to control salmonberry or western thimbleberry shrubs. Aerial spray tests indicate that combinations of dicamba with 2,4,5-T may be useful for site preparation. Herbicidal treatments for conifer release and site preparation are recommended for each species." (A)

550. Stewart, R. E.

1974. Foliage sprays for site preparation and release from six coastal brush species. USDA For. Serv. Res. Pap. PNW-172, 18 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Fifteen herbicides or combinations of herbicides were tested as ground-applied foliage sprays on red alder, salmonberry, western thimbleberry, vine maple, California hazel, and salal. Picloram produced the best overall control of the six species, although not even picloram produced acceptable control of salal. Foliage sprays of 2,4,5-T were effective on all species except salal. Herbicides were generally more effective when applied in late spring than in midsummer. However, adequate control for release of conifers can be obtained with midsummer sprays of 2,4,5-T on red alder, salmonberry, and western thimbleberry. Herbicidal treatments suitable for conifer release and site preparation are recommended for each species." (A)

551. Stewart, W. D. P.

1962. A quantitative study of fixation and transfer of nitrogen in Alnus. J. Exp. Bot. 13(38):250-256.

"In Alder [A. glutinosa?] plants during the first season's growth, N fixation per plant reached a maximum in late

August, but fell rapidly with the onset of autumn. Fixation per unit dry weight of nodule tissue was greatest in young nodules and was of the same order as in nodulated legumes. Throughout the growing season there was a steady transfer from the nodules of some 90% of the N fixed. The rate of fixation relative to the growth of the endophyte is much higher than in free-living N-fixing organisms, and is clearly governed by the N requirements of the entire symbiotic system. These findings are compatible with the view that the fixation process is extracellular to the endophyte." (FA)

552. Stewart, W. D. P.  
1967. Nitrogen-fixing plants.  
Science 158(3807):1426-1432.

"A review, discussing the legume/Rhizobium association, the non-leguminous nitrogen-fixing plants and their symbionts (algae or bacteria), and the biochemical aspects of nitrogen reduction." (FA)

553. Stubblefield, George, and Chadwick D. Oliver.  
1978. Silvicultural implications of the reconstruction of mixed alder/conifer stands. In Utilization and management of alder, p. 307-320. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Mixed alder hemlock redcedar Douglas-fir stands which began growth after a 1927 logging fire were studied on till soils of the Marchworth Forest of the central Washington Cascades. The stand was

always sparsely stocked. Essentially all stems had begun within 20 years of the disturbance. Red alders were the same age or up to 17 years younger than the associated conifers on the same plot, although the conifers were usually in a subordinate position. For analyses of site index, stocking, and growth rates, it cannot be assumed that the alders are the same age as the initiating disturbance. The alders varied widely in crown size and diameter but varied less in height. Basal area of individual alders was closely related to spacing. Closely spaced alders resulted in spindly stems of poor quality. Very recent alder stands generally begin with many more stems per acre than this stand did. Early thinning may be necessary to achieve adequate alder growth." (A)

554. Stuntz, D. E., and E. C. Seliskar.  
1943. A stem canker of dogwood and madrona. Mycologia 35(2):207-221.

"During the past few years Cornus nuttallii and Arbutus menziesii trees in Seattle and the vicinity have become increasingly affected by cankers which girdle the stem and eventually kill the tree. When tissues from cankers on both tree species were incubated, two organisms were obtained:--a Phomopsis, later found to be a secondary parasite, and a species of Phytophthora, identified as P. cactorum. This is the first record of P. cactorum on these hosts.

"The fungus was found by inoculation tests to be quite virulent on Acer macrophyllum and able to attack Pseudotsuga taxifolia, Alnus rubra, Salix scouleriana, and Corylus californica." (FA)

555. Sudworth, George B.  
1908. Forest trees of the Pacific slope. 441 p. Washington, D.C.
556. Sund, Jimmie Damon.  
1977. Some responses of red alder to herbicide application. M.S. thesis. Univ. Wash., Seattle. 60 p.
- "Under conditions of this study, relative humidity and interactions of relative humidity with plant moisture stress or temperature explained or were associated with 50 percent of the variation in control of red alder by 2,4-D. Best control was obtained under conditions of high relative humidity during the morning hours, if foliage was not overly wet; or under conditions of rising relative humidity during the late afternoon. Timing of diurnal transport of carbohydrates and herbicide to the roots and rates of respiration along the transport route appear to be additional factors as they relate to plant water relations and temperature. The period of poorest control was during the midday depression between 1:00 p.m. and 4:00 p.m. when relative humidity was below 50% and a plant moisture stress of 15 atmospheres." (A)
557. Swan, Eric P.  
1973. Resin acids and fatty acids of Canadian pulpwoods-- a review of the literature. West. For. Prod. Lab. Inf. Rep. VP-X-115, 21 p. Can. For. Serv., Vancouver, B.C.
- "The literature on the fatty acids and resin acids, and bound forms of these acids, found in Canadian pulpwoods is reviewed. Data for the following trees are presented: jack pine, lodgepole pine, ponderosa pine, red pine, eastern white pine, radiata pine, western larch, tamarack, white spruce, Sitka spruce, Norway spruce, western hemlock, Douglas-fir, alpine fir, amabilis fir, western red cedar, red alder, red maple, sugar maple, silver birch, trembling aspen, white elm, white and yellow birch and basswood.
- "Further research on a variety of important variables and on unreported species is discussed." (A)
558. Szczawinski, Adam F., and Antony S. Harrison.  
1972. Flora on the Saanich Peninsula: Annotated list of vascular plants. Occas. Pap. B.C. Prov. Mus. 16, 114 p. Victoria, B.C.
- Red alder is among the species listed. (CFH)
559. Tarrant, R. F.  
1972. The role of alder in improving soil fertility and growth of associated trees. In Managing young forests in the Douglas-fir region, Vol. 3, p. 17-34. Alan B. Berg, ed. Sch. For., Oreg. State Univ., Corvallis.

560. Tarrant, Robert F.

1961. Stand development and soil fertility in a Douglas-fir-red alder plantation. *For. Sci.* 7(3):238-246.

"Douglas Fir planted (8 X 8 ft.) at 2000 ft. was interplanted in part 4 years later with 2-year Alnus rubra from seed collected at 100 ft. alt., the latter plants suffering early from frost. The following advantages for the mixture at 27 years are shown from plot and sample-tree studies. The volume (Alder and Douglas) was more than twice that of pure Douglas, with no adverse effect on stem size and with an adequate stem number of Douglas (443/acre). Dominant Douglas grew faster in diam. and height over the years 20-27. Form class and upper crowns of Douglas were better. Total N in soil and in Douglas foliage was also greater. The Alder has evidently contributed to increased growth in Douglas dominants from age 20." (FA)

561. Tarrant, Robert F.

1964. Forest soil improvement through growing red alder (Alnus rubra Bong.) in Pacific Northwestern United States. 8th Int. Congr. Soil. Sci. Trans. V:1029-1043. Bucharest, Rumania.

562. Tarrant, Robert F.

1968. Some effects of alder on the forest environment. (Abstr.) In *Biology of alder*, p. 193. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

563. Tarrant, Robert F.

1978. Attitudes toward red alder in the Douglas-fir region. In *Utilization and management of alder*, p. 1-7. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"A positive change in attitudes toward purposeful management of red alder is increasingly evident. Reasons for this change include critical problems of wood fiber supply and increasing costs of fertilizer materials. Several possibilities for exploiting red alder in forest management programs are discussed in light of its rapid early growth rate and ability to improve soil fertility. Additional research must be done, both in the physical and biological sciences if we are to capture the unique attributes of red alder in improved forest management systems. Red alder must be considered a tree of high potential value in a mature forest economy." (A)

564. Tarrant, Robert F., Leo A. Isaac, and Robert F. Chandler, Jr.

1951. Observations on litter fall and foliage nutrient content of some Pacific Northwest tree species. *J. For.* 49(12):914-915.

"Gives annual oven-dry weight of litter fall, nutrient content of foliage (lb./ acre), and soil pH at 3 depths under the following species: Thuja plicata, Pseudotsuga taxifolia (100 and 350 years old), Abies amabilis, Acer macrophyllum, Pinus monticola, Alnus rubra, Tsuga heterophylla, Picea sitchensis, Pinus ponderosa (100 and 350 years old), and Pinus contorta var. latifolia." (FA)

565. Tarrant, Robert F., K. C. Lu, W. B. Bollen, and C. S. Chen.  
1968. Nutrient cycling by through-fall and stemflow precipitation in three coastal Oregon forest types. USDA For. Serv. Res. Pap. PNW-54, 7 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Throughfall and stemflow were collected beneath three adjacent forest types--red alder; conifer--Douglas-fir, western hemlock, and Sitka spruce; and a mixture of alder and conifer. Weight of N and dissolved solids in stemflow was insignificant because of small amounts of stemflow and soil area affected. Nutrient cycling rates differ appreciably between the three forest types." (A)

566. Tarrant, Robert F., K. C. Lu, W. B. Bollen, and J. F. Franklin.  
1969. Nitrogen enrichment of two forest ecosystems by red alder. USDA For. Serv. Res. Pap. PNW-76, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"In a study of 40-year-old forests on the Oregon coast, a natural mixed stand of Red Alder and conifers (a) contained 860 trees/acre and had a litter-fall of 5930 lb./acre; corresponding figures for a pure conifer (Douglas Fir, Western Hemlock and Sitka Spruce) stand (b) were 490 trees and 4232 lb./acre, and for pure Alder (c) 381 trees and 4490 lb./acre. In each, the weight of litter varied with the season (significantly for all three stands) and the year (significantly in (b) but not in (a) or (c)); this latter variation is attributed to variations in the weather between years. The seasonal effect varied from year to year. In all stands the N% of the litter-fall varied with season and year and the season/year interaction was

highly significant. Over three years, the average N% in the litter-fall of (c) was nearly three times and that in (a) more than twice that in (b). The average weight of N in the annual litter-fall was (a) 104, (c) 100 and (b) 32 lb./acre. Net annual addition of N fixed by Red Alder and returned in litter is estimated at ca. 72 lb./acre in (a) and 68 in (c). Over all years and seasons, the C/N ratio averaged 69 on (b), 27 on (c) and 32 on (a). The silvicultural value of Red Alder in enhancing soil fertility is discussed." (FA)

567. Tarrant, Robert F., and Richard E. Miller.  
1963. Accumulation of organic matter and soil nitrogen beneath a plantation of red alder and Douglas-fir. Soil Sci. Soc. Am. Proc. 27(2):231-234.

"Soil nitrogen accumulation beneath a plantation of red alder and Douglas-fir was compared with that under a pure fir segment of the same 30-year-old stand on the Wind River Experimental Forest in southwestern Washington.

"Beneath the mixed plantation, there were significantly greater amounts of nitrogen in the forest floor and in the upper 24 inches of the mineral soil. Organic matter content in the upper 12 inches of mineral soil was also greater and bulk density at 0 to 3 inches was significantly less. Beneath the alder-fir stand, the carbon-nitrogen ratio was less, both in the forest floor and at 0 to 3 inches.

"There were 938 pounds more N per acre to depth of 36 inches under the alder-fir plantation. Consequently, an average of 36 pounds more soil N per acre per year has accumulated beneath the mixed stand than under pure fir." (A)

568. Tarrant, Robert F., and James M. Trappe.

1971. The role of *Alnus* in improving the forest environment. *Plant and Soil, Spec. Vol.* 1971:335-348.

"Worldwide experiences indicates that alder contributes significantly to the supply of nitrogen in the ecosystem. This contribution markedly benefits soil fertility. A definite potential exists for employing alder in forest management in much the same way that legumes are utilized in agriculture. Current research indicates also that *Alnus rubra* may play a significant role in controlling *Poria weiri*, a virulent root pathogen which causes extensive losses of commercial timber tree species in western North America and Japan." (A)

569. Taylor, Roy L., and Bruce MacBryde. 1977. Vascular plants of British Columbia: A descriptive resource inventory. *Tech. Bull.* 4, 754 p. Bot. Gar. Univ. B.C., Vancouver.

Describes *Alnus rubra* on page 126. Useful information on biology and chromosome complement of red alder. (CFH)

570. Tehon, L. R.

1943. Canker of Pacific dogwood and madrona. *Am. Nurseryman* 77(7):18-19.

"Pacific Dogwood (*Cornus nuttallii*) and Madrona (*Arbutus menziesii*) are sometimes attacked by *Phytophthora cactorum* which causes a girdling canker and which may kill the tree. Inoculation experiments resulted in very large cankers on these species after a period of 13 weeks, and also showed the following species to be

more or less susceptible to the disease: --Oregon Maple (*Acer macrophyllum*), Red Alder (*Alnus rubra*), Scouler Willow (*Salix scouleriana*), California Hazel (*Corylus californica*), and Douglas Fir (*Pseudotsuga taxifolia*). A method of treatment by removing the canker (scarification) is described." (FA)

571. Tessier, J. P., and J. H. G. Smith. 1961. Effect of tree size of red alder on harvesting and conversion of lumber. *Fac. For. Res. Pap.* 45, 8 p. Univ. B.C., Vancouver.

"A logging study was made on two 5-acre blocks--(a) only hardwoods cut, (b) clear felled--and a mill study on ninety-four 12-ft. logs. It is concluded that, under the conditions of this study, *Alnus rubra* trees <11 in. d.b.h., and logs <8 in. top diam. u.b. cannot be harvested and converted at a profit." (FA)

572. Tilton, Donald L., and John M. Bernard.

1975. Primary productivity and biomass distribution in an alder shrub ecosystem. *Am. Midl. Nat.* 94(1):251-256.

"Net primary productivity of an alder [*Alnus rugosa* (Du Roi) Spreng.] tall-shrub community in the S-central Finger Lakes region of New York was estimated by a stratified sampling method. The total aboveground dry weight production of alder was  $730 \text{ g/m}^2/\text{year}$ . Leaves and twigs represented 42% of total production; 25% was in the bole; 21% in

branches, and 12% in fruits. These values varied with size class, with the greatest variation in fruit production. The herbaceous layer contributed 241 g/m<sup>2</sup>/year to a total aboveground production of 972 g/m<sup>2</sup>/year. This relatively high production value is thought to be due in part to symbiotic nitrogen fixation in alder root nodules and to favorable soil moisture and oxygen levels." (A)

573. Timberman.

1946. New use for over-ripe alder.  
Timberman 48(2):70.

574. Timberman.

1957. Western hardwood panels with fir cores studied. Timberman  
58(1B):105.

575. Timberman.

1958. Preparing site posed problem on this western tree farm.  
Timberman 59(2):43, 55-56.

"The reclamation of 60,000 acres of twice-logged, constantly fired Alder and brush (15% of Weyerhaeuser Timber Co.'s tree farm at Clemons, Wash.) involved: aerial and ground survey to map vegetation and distinguish the unmerchantable Alder; the use of T-D 24 crawler tractors for constructing roads (300 miles) and heliports (1 mile apart), for scarifying ground (\$25/acre) and clearing brush (1.0-1.5 acre/hour); aerial spraying of unmerchantable Alder with 2,4-D or 2,4,5-T at 5 gal./acre; logging the rest under contract, with bonuses for snags; free shooting of deer; and sowing with helicopters of repellent- (not poison-) treated Douglas Fir seed at 1 lb./acre. The helicopter capacity is 400 lb. of

seed. It sows, from 200 ft. at 50 m.p.h., a 90-ft. strip, and costs for criss-cross sowing are \$2/acre. An area of 70,000 acres is sown in 75 hours. On scarified ground 2700-5500 seedlings/acre are obtained, of which 3000 are expected to become established." (FA)

576. Trappe, James M.

1972. Regulation of soil organisms by red alder: A potential biological system for control of Poria weiri. In Managing young forests in the Douglas-fir region, Vol. 3, p. 35-61. Alan B. Berg, ed. Sch. For., Oreg. State Univ., Corvallis.

"Analysis of field samples and lab. tests indicate that red alder (Alnus rubra) produces Poria inhibiting compounds that are added to the soil and could reduce longevity of the pathogen in buried inoculum. Such compounds, with the relatively high N levels under alder and the lack of a food base in the resistant alder, result in a selective increase in populations of organisms actively competing with, inhibiting, or parasitizing P. weiri." (MO)

577. Trappe, James M.. Jerry F.

Franklin, Robert F. Tarrant, and George M. Hansen, eds.  
1968. Biology of alder. (Proceedings of a symposium held at Northwest Scientific Association 40th annual meeting, Pullman, Washington, April 14-15, 1967.) 292 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Papers (or their abstracts) read are divided into five sections--(1) Taxonomy and distribution: Disjunct populations of Red Alder in Idaho, and Taxonomy and

distribution of northwestern Alders (both by F. D. Johnson); Relationships of allied species between northwestern U.S.A. and Japan on the genus Alnus (S. Murai). (2) Ecology: Comparison of vegetation in adjacent Alder, conifer, and mixed Alder-conifer communities. I. Understory vegetation and stand structure (J. F. Franklin and A. A. Pechanec); On the ecology of Sitka Alder [Alnus crispula subsp. sinuata] in the subalpine zone of south-central Alaska (W. W. Mitchell); A comparison of rhizosphere microfloras associated with mycorrhizae of Red Alder and Douglas Fir (J. L. Neal et al.); Role of Red Alder in western Oregon forest succession (M. Newton, B. A. el Hassan, and J. Zavitkovski); Comparison of vegetation in adjacent Alder, conifer and mixed Alder-conifer communities. II. Epiphytic, epixylic and epilithic cryptogams (A. A. Pechanec and J. F. Franklin); First-season growth of Red Alder seedlings under gradients in solar radiation (R. H. Ruth); Germination analysis of Grey Alder (Alnus incana) and Black Alder (Alnus glutinosa) seeds (I. Schalin); Soil development and Alder invasion in a recently deglaciated area of Glacier Bay, Alaska (F. C. Ugolini). (3) Soil and microbiological relationships: Nitrogen transformations in soils beneath Red Alder and conifers (W. B. Bollen and K. C. Lu); Effect of stemflow precipitation on chemical and microbiological soil properties beneath a single [Red] Alder and conifers (J. F. Franklin et al.); Comparison of microbial populations between Red Alder and conifer soils (K. C. Lu, C. S. Chen and W. B. Bollen); Some ectotrophic mycorrhizae of Alnus rubra (J. L. Neal et al.); Nodule endophytes in the genus Alnus (C. Rodriguez-Barreco and G. Bond); Some effects of Alder on the forest environment (R. F. Tarrant); Resistance of Alnus rubra to infection by the root rot fungus

Poria weiri (G. Wallis); On the influence of Alder (Alnus inokumae) on soil properties in northern Japan (K. Yamaya); Effect of organic matter and combined nitrogen on nodulation and nitrogen fixation in Red Alder (J. Zavitkovski and M. Newton). (4) Physiology: Red Alder deficiency symptoms and fertilizer trials (D. R. Hughes, S. P. Gessel and R. B. Walker); Photosynthesis of Red Alder, Douglas-Fir, Sitka Spruce and Western Hemlock seedlings (K. W. Krueger and R. H. Ruth); Enzyme systems of Red Alder and Douglas-Fir in relation to infection by Poria weiri (C. Y. Li et al.); Hypoxylon fuscum: a review of the fungus and its relationship with Alnus in the northwest (J. F. Rogers); The effect of cobalt and certain other trace metals on the growth and vitamin B<sub>12</sub> content of Alnus rubra (S. A. Russell, H. J. Evans and P. Mayeux). (5) Growth and yield: Growth and yield of Red Alder in British Columbia (J. H. G. Smith); Productivity of Red Alder in western Oregon and Washington (R. L. Williamson)." (FA)

578. Trappe, James M., C. Y. Li, K. C. Lu, and W. B. Bollen.  
1973. Differential response of Poria weiri to phenolic acids from Douglas-fir and red alder roots.  
For. Sci. 19(3):191-196.

"In previous studies the phenolic acids, p-coumaric, ferulic, syringic, and vanillic, have been quantitatively determined from hydrolyzed extracts of

red alder roots, and p-coumaric and vanillic, from Douglas-fir roots. Alder roots resist infection by Poria weiri, whereas Douglas-fir roots are highly susceptible. In the present study, the compounds alone and in all combinations were tested for effects on growth of two genotypes of P. weiri in vitro. The combination of all compounds, as found in alder root hydrolysates, inhibited growth of both Poria isolates. The p-coumaric-vanillic combination associated with Douglas-fir root hydrolysates inhibited one isolate and stimulated the other. The two isolates differed markedly in response to several other combinations of the compounds and in their effects on pH of the medium. Phenolic substances probably participate in the Poria-resistance system of alder. Physiological strains of P. weiri that effectively attack any susceptible host may exist, but not all strains are likely to be equally pathogenic on all hosts or all root parts of a host (bark vs. sapwood vs. heartwood, for example). Biological control of P. weiri, seeming anomalies in behavior of P. weiri in nature, and breeding for host resistance are discussed." (A)

579. Triska, F. J., J. R. Sedell, and B. Buckley.

1975. The processing of conifer and hardwood leaves in two coniferous forest streams: II. Biochemical and nutrient changes. Verh. Int. Ver. Limnol. 19(3):1628-1639.

"Leaf material, as it entered the stream, underwent leaching and microbial colonization. This process, called conditioning, rendered allochthonous debris

palatable to stream invertebrates. This conditioning process also resulted in increased concentration of certain essential nutrients such as N and P. Concentration increases were highest in the larger stream with the more active microbial flora. The cost of conditioning was some qualitative deterioration of carbon quality for detritus-consuming invertebrates.

"Faster leaf processing was observed in Mack Creek, the larger stream, when compared to Watershed 10 by all measured parameters, weight loss, nutrient immobilization, carbon quality, and microbial respiration. The mechanism for faster microbial processing remains obscure. Such data indicate the need for a more thorough examination of the physical, chemical, and biological properties of the soil-water interface." (A)

580. Tschirley, F. H., Ed.

1956. Undesirable woody plants. West. Weed Control Conf. Res. Prog. Rep. 1956:26-42.

"... Alnus rubra was readily controlled by basal treatments with 2,4,5-T alone or with 2,4-D (esters). ..." (FA)

581. Tuckerman, E.

1843. Observations on some interesting plants of New England. Am. J. Sci. Ser. 2, 45:27-49.

Alnus serrulata is described as A. rubra. This is an obsolete synonym but can cause confusion in older literature. (CFH)

582. Turnbull, K. J., Gene R. Little, and Gerald E. Hoyer  
1963. Comprehensive tree-volume tarif tables. 23 p. Wash. State Dep. Nat. Resour., Olympia.

"The tables contain both cubic and board-foot volume to various minimum top diameters, and also volume/b.a. ratios and growth multipliers to estimate annual volume growth from increment cores, based on field work in Washington State. 'Access tables' for selecting the correct tariff for Douglas Fir, Ponderosa Pine, Western Hemlock and Red Alder are included." (FA)

583. Turner, J., D. W. Cole, and S. P. Gessel.  
1976. Mineral nutrient accumulation and cycling in a stand of red alder (Alnus rubra). J. Ecol. 64(3):965-974.

"The distribution of organic matter and mineral nutrients in a thirty-four-year-old stand of red alder (Alnus rubra) in Washington State, U.S.A., is described, together with the annual nutrient transfers between components. The nutrients studied were nitrogen, phosphorus, potassium, calcium, magnesium and manganese. There was a large quantity of N in the ecosystem, presumably because of N-fixation by the alder. The stand was deteriorating and thus there was a high quantity of wood in the litterfall. The understorey made an important contribution to the biomass, stand productivity and return of mineral nutrients to the forest floor. Comparison with a nearby stand of Douglas-fir (Pseudotsuga menziesii) of similar age indicates that, while the organic matter distribution is similar, they have different patterns of nutrient accumulation and cycling. Data

from an overmature 450-year-old Douglas-fir stand are also included so that a comparison of two deteriorating stands can be made." (A)

584. Turner, John, and Dale W. Cole.  
1973. A review of forest biomass accumulation. Coniferous For. Biome Intern. Rep. 56, 43 p. Univ. Wash., Seattle.

585. Turner, Nancy J.  
1975. Food plants of British Columbia Indians: Part 1--Coastal peoples. B.C. Prov. Mus. Handb. 34, 264 p. Victoria, B.C.

586. U.S. Department of Agriculture, Agricultural Research Service.  
1960. Index of plant diseases in the United States. U.S. Dep. Agric. Agric. Handb. 165, 531 p. Washington, D.C.

A list of more than 1,200 host genera and 50,000 parasitic and nonparasitic diseases arranged by host. Useful annotation on some diseases. (CFH)

587. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.  
1950. Veneer cutting and drying properties. Red alder (Alnus rubra). For. Prod. Lab. Rep. D1766-2, 2 p. Madison, Wis.

"Laboratory tests covering the preparation of logs for cutting, suitable lathe settings, and veneer drying, were made on bolts of Red Alder (Alnus rubra).

The wood was found to be in excellent condition for cutting after washing in water at 140° F. for about 8 hr. for a 12-in. and 15 hr. for a 16-in. bolt, both 4 ft. long. It is possible that good veneer could be cut from unheated wood, and heating in steam would probably result in overheating. A thorough study of lathe settings has not been made, but settings that produce tight, smooth veneer are given for 3 veneer thicknesses. The green veneer varied in moisture content from 71 to 105%. At a temperature of 250°, the 1/32- and 1/24-in. veneer dried in 5 minutes to a moisture content of 2-3%; it was rather brittle and split in handling. The 1/16-in. veneer dried in 8 min. to about 5%. Tangential shrinking based on green width was about 7%." (FA)

588. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.  
1958. Factors that influence the decay of untreated wood in service and comparative decay resistance of different species. For. Prod. Lab. Rep. 68, 6 p. Madison, Wis.

Discusses in general terms factors influencing decay of wood: moisture, air, warmth, heartwood and sapwood, amounts of natural preservatives, season of culling, and seasoning and servicing conditions. Alder is considered slightly resistant or nonresistant to decay. (CFH)

589. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.  
1973. Standard terms for describing wood. USDA For. Serv. Res. Note FPL-0171, 12 p. For. Prod. Lab, Madison, Wis.

"Presents series of standards for describing specific gravity, shrinkage, bending and compressive strength, hardness, shock resistance, and stiffness of the various species of wood as developed by the U.S. Forest Products Laboratory." (A)

590. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.  
1974. Wood handbook: Wood as an engineering material. U.S. Dep. Agric. Agric. Handb. 72, 528 p. Washington, D.C.

Basic information on wood as a material for construction, with data for its use in design and specifications. Also a 1955 edition. (CFH)

591. Uemura, S.  
1971. Non-leguminous root nodules in Japan. Plant and Soil, Spec. Vol. 1971:349-360.

"Among plants native to Japan, nodule formation is confirmed in 14 species and varieties of *Alnus*, 10 of *Elaeagnus*, 2 of *Myrica* and 1 of *Coriaria*, in a number of instances for the first time. Plants of 20 foreign species, in 8 genera, which bear nodules in their native countries, were raised in the nursery in Tokyo; only species of *Alnus*, *Myrica* and *Ceanothus* formed nodules. No nodules were found on native plants of *Dryas octopetala* var. *asiatica*.

"In a trial extending over 12 years evidence was obtained that the growth of Pinus thunbergii was benefited by under-planting with Myrica rubra, a result attributed to nitrogen fixation in the root nodules of the latter species.

"In the attempted isolation of the endophytes from the nodules of Alnus and other non-legume Angiosperms, although actinomycetes peculiar to the host species were usually obtained from the nodules, none of the isolates induced nodules in re-inoculation tests. Also from Podocarpus nodules actinomycetal and bacterial strains were commonly isolated; re-inoculation tests with these are in progress." (A)

592. Ulrich, B.  
1962. [Fifteen years experience with poplar and red alder in the Danndorf Forest Administration.]  
Holzzucht 16(1/2):4-7.

593. United Kingdom Forestry Commission.  
1964. Report on forest research for the year ended March 1974.  
109 p. Her Majesty's Stationery Off., London.

"Provenance trials in progress are reported for Picea sitchensis, P. Englemannii, P. Abies, Pinus contorta, Abies grandis, and Alnus rubra." (PO)

594. Vancura, V., and G. Stotzky.  
1976. Gaseous and volatile exudates from germinating seeds and seedlings. Can. J. Bot. 54(5-6):518-532.

"The quantities of gaseous and volatile metabolites liberated by germinating seeds and seedlings appeared to be

related, in general, to the amount of storage substances present in the seeds. Both qualitative and quantitative differences were found between various plant species and varieties of both angiosperms and gymnosperms. The release of volatile compounds preceded the appearance of the first root and, with most seeds, was greatest in the first 24 to 48 h. Organic volatiles could be detected, by gas chromatography, in as little as 5% of the atmosphere from one germinating seed. All seeds that were studied liberated ethanol, and most seeds evolved methanol, formaldehyde, acetaldehyde, formic acid, ethylene, and propylene. Propionaldehyde and (or) acetone was also evolved by cotton, pea, and yellow pine. The possible source of these volatile metabolites and their ecological implications are discussed."(A)

595. van Dijk, C., and E. Merkus.  
1976. A microscopical study of the development of a spore-like stage in the life cycle of the root-nodule endophyte of Alnus glutinosa (L.) Gaertn. New Phytol. 77(1):73-91.

"A light- and electron-microscopical study of the root-nodule endophyte of Alnus glutinosa (L.) Gaertn. was carried out to investigate the development of a spore-like stage, here called the granule, in the life cycle of the endophyte. Comparison of granule-rich and granule-free root nodules showed that granule formation takes place via local transverse growth of thick endophytic hyphae, giving rise to multicellular 'granulated bodies' differing in shape and size. Subsequently, the cells of these granulated bodies are transformed into

granules by cell separation and ultrastructural changes, the most striking of which are cell-wall thickening, reduction of the number of mesosomes, and increased density of the cytoplasm. Granule development takes place both intracellularly and intercellularly. Intracellularly produced granules are eventually liberated by the death of the host cell. Mature granules show a strong resemblance to spores of free-living actinomycetes in their ultrastructure and behavior.

"It is concluded that, in view of the terminology currently used in the description of members of the Actinomycetales, the term granule should be replaced by spore and thus the term granulated body by sporogenous body." (A)

596. Vanosdoll, John Clark.  
1977. Red alder whole-tree chipping characterization in relation to kraft pulping. M.S. thesis. Univ. Wash., Seattle. 37 p.

The biggest problem in utilizing whole-tree chips is bark contamination; the more bark in the chip supply, the lower the yield and the higher the kappa number of resulting pulps. Successful utilization of whole-tree chips will require development of methods to allow mills to adapt to the varying chip supply. The bark content of a chip supply and lignin were found to correlate with the screened pulp yield of corresponding kraft cooks. Lower yields are accompanied by increases in black liquor solids and British thermal unit per pound of oven-dry solids, reduced digestor output and decreases in production. These plus an increased alkali demand increase costs of pulp production. Other

problems, such as wear from sand and grit in bark, and possible overloading of the recovery furnace caused by an increased load of black liquor solids is also important. (CFH)

597. Viereck, Leslie A., and Elbert L. Little, Jr.  
1972. Alaska trees and shrubs. U.S. Dep. Agric. Agric. Handb. 410, 265 p. Washington, D.C.

A description of the woody species of Alaska. Includes separate summer and winter keys for Alaska trees and for shrubs; illustrations, range maps; and discussions of botanical and silvicultural features. (CFH)

598. Viereck, Leslie A., and Elbert L. Little, Jr.  
1974. Guide to Alaska trees. U.S. Dep. Agric. Agric. Handb. 472, 98 p. Washington, D.C.

"Alaska's native trees, 32 species, are described in nontechnical terms and illustrated by drawings for identification. Six species of shrubs rarely reaching tree size are mentioned briefly. There are notes on occurrence and uses, also small maps showing distribution within the State. Keys are provided for both summer and winter, and the summary of the vegetation has a map. This new Guide... is condensed and slightly revised from 'Alaska Trees and Shrubs' (1972) [(592)] by the same authors." (A)

599. Virtanen, A. I., T. Moisio, R. M. Allison, and R. H. Burris.  
1955. Fixation of nitrogen by excised nodules of the alder. Acta Chem. Scand. 9:184-186.

600. Virtanen, Artturi I.

1957. Investigations on nitrogen fixation by the alder. II. Associated culture of spruce and inoculated alder without combined nitrogen. *Physiol. Plant.*, Copenhagen 10(1):164-169.

"Seedlings of Picea abies were grown from 1931 to 1942 in quartz sand in association with seedlings of Alnus glutinosa that had been inoculated with a water suspension of crushed Alder root nodules. No combined N was added; but the test plants were watered with a nutrient solution of  $MgSO_4$ ,  $KCl$ ,  $KH_2PO_4$ ,  $CaCO_3$  and tapwater. All fallen Alder leaves were removed from the soil surface. After 7 years, seedlings of both species were analysed to determine the amounts of dry matter and the N content of different parts of the plant. Results are tabulated. Results of analyses after 11 years were lost during the war but photos show the growth of both species. Spruce obtained N fixed in the nodules of Alder roots even during its first years of growth. Data are given on the amount of N fixed by Alder after 7 years." (FA)

601. Vockeroth, J. R.

1974. Notes on the biology of Cramptonomyia spenceri Alexander (Diptera:Cramptonomyiidae). *J. Entomol. Soc. B.C.* 71:38-42.

"Adults of Cramptonomyia spenceri were abundant in the lower Fraser Valley, British Columbia, from late February to early April of 1973. Eggs, larvae and pupal skins were found on or in dead fallen stems of Alnus rubra. Wing frequency measurements of both sexes indicate that auditory stimuli are not involved in finding of mates." (A)

602. Voigt, G. K.

1965. Nitrogen recovery from decomposing tree leaf tissue and forest humus. *Soil Sci. Soc. Am. Proc.* 29(6):756-759.

"Recovery of N from decomposing leaf litter of alder (Alnus rugosa [Du Rois] Spring.), dogwood (Corus florida L.), tulip poplar (Liriodendron tulipifera L.), hemlock (Tsuga canadensis [L.] Carr.), eastern redcedar (Juniperus virginiana L.), and red pine (Pinus resinosa Ait.) was studied under laboratory and greenhouse conditions. Weight loss and N deficits in decomposing tissue were more marked in hardwoods than in conifers. There was no pronounced species correlation between Ca concentration of the leaf litter and either weight loss or N deficit, but N deficit was increased in some cases by addition of  $CaCO_3$ . Considerable variation in availability of N to Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) seedlings was observed in soil cultures where N originated from decomposing leaf tissue or from humus samples collected under the aforementioned species. Recovery of N ranged from about 60 to over 90% of the original N content." (A)

603. Voigt, G. K., and G. L. Steucek.

1969. Nitrogen distribution and accretion in an alder ecosystem. *Soil Sci. Soc. Am. Proc.* 33(6):946-949.

"Analysis of plant and soil components of an alder (Alnus rugosa [Du Rois] Spreng.) community that had invaded the bed of an abandoned mill pond showed an average annual N accretion of about 85 kg/ha. Most (93%) of the N in the ecosystem was found in the soil and there was a strong

correlation between soil moisture content and N concentration. This may have resulted in part from more favorable conditions for nodule functioning. The amount of N in the alder stand during the growing season was about equal to that contained in freshly fallen litter. About three-fourths of the N in alder plants was found in stems and twigs but highest concentrations of N were found in leaves and nodules." (A)

604. Voorhies, Glenn.

1944. The essentials of kiln drying Oregon hardwood lumber. Oreg. For. Prod. Lab., Res. Leafl. 2, 17 p. Corvallis.

605. Voth, Elver H., and Hugh C. Black. 1973. A historic technique for determining feeding habits of small herbivores. J. Wildl. Manage. 37(2):223-231.

"The mountain beaver (Aplodontia rufa) was used in a feeding experiment involving 20 species of vascular plants. A foliar epidermal digestibility characteristic was measured. A fecal recognition item was a flat epidermal fragment that measured at least 0.1 mm in at least one direction. The number of recognition items per gram of dry weight of each plant eaten in captivity was determined and divided into a standard number, which was the number (11.0) of fragments counted per gram (dry weight) of sword-fern (Polystichum munitum) ingested. The resulting conversion factor was called an equivalence factor.

The equivalence factors varied through a 15-fold range--from 0.8 for red alder (Alnus oregonia) to 12.2 for western spring beauty (Montia sibirica). The conversion factors increase the accuracy of relative volumetric estimates of food intake based on histologic analysis of fecal samples collected in the field. Conversion factors can be predicted by correlating equivalence factors with moisture content and reading factors for unknown plants from a line of regression when the percentage dry weight of the plant has been determined." (A)

606. Voth, Elver Howard.

1968. Food habits of the Pacific mountain beaver, Aplodontia rufa pacifica Merriam. Ph. D. thesis. Oreg. State Univ., Corvallis. 276 p.

"The mountain beaver causes heavy loss in the Pacific Northwest, primarily to Douglas Fir, by clipping or burying seedlings during burrowing and by pruning or girdling older trees. A study of a heavy population and its annual consumption of vegetation in a 2-ha. site with alder succession problems in the Oregon Coast Range in 1964-66 showed that sword-fern or bracken (neither much eaten by deer) form 82% of the diet of the adult." (FA)

607. Wagener, Willis W., T. W. Childs, and J. W. Kimmey. 1949. Notes on some foliage diseases of forest trees on the Pacific slope. Plant Dis. Rep. 33(4):195-197.

608. Waggener, Thomas R.  
1978. Should alder be replaced by conifers? In Utilization and management of alder, p. 365-379. David G. Briggs, Dean S. DeBell, and William A. Atkinson, compilers. USDA For. Serv. Gen. Tech. Rep. PNW-70. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- "As with most hypothetical questions, the question of whether alder should or should not be replaced with conifer must be answered ambiguously. It is assumed that this basic question will be approached from an economic or financial point of view.
- "Application of financial analysis to the question of site conversion requires two basic sets of information: 1) biological response data relevant to the management options to be considered, and 2) present and future values for both costs and returns for each management option, including the relevant cost of capital.
- "A primary consideration in the analysis of site conversion is the determination of yield responses from management. Also, projected time trends in both yield values and costs need to be carefully considered, since both management and feasibility and the comparative advantage of an optimal management program can change greatly under such trends. Because of the long financial production periods, the cost of time is often a major determinant of economic feasibility.
- "Examples for generalized site conversion analysis are reviewed and the implications of the major management variables are discussed. The application of these approaches requires each manager to carefully assess the specifics of his forest land and the site-specific cost and value relationships." (A)
609. Wall, Brian R.  
1969. Projected developments of the timber economy of the Columbia-North Pacific region. USDA For. Serv. Res. Pap. PNW-84, 87 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- Economic projections of the forest industry of the Northwest through 2020. Extensive tables describe commercial and private forest area, forest industry employment income, volumes of growing stock by species, etc. (51 tables). (CFH)
610. Wallis, G.  
1968. Resistance of Alnus rubra to infection by the root rot fungus Poria weiri. In Biology of alder, p. 195. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- "Attempts at inoculating red alder roots with cultures of Poria weiri plus studies of excavated root systems indicated that alder is not susceptible to sustained infection by this pathogen." (A)
611. Wallis, G. W., and G. Reynolds.  
1962. Inoculation of Douglas fir roots with Poria weiri. Can. J. Bot. 40(5):637-645.
- "A method for the inoculation of Douglas-fir roots with Poria weiri using Douglas fir, alder, maple, and oak wood for preparing the inoculum is described. When the deciduous wood was used as the food base on which the fungus was grown, a higher percentage of infection was

achieved than when either Douglas fir stem or roots were used. Six months was sufficient time for the fungus to become well established on the bark surface; penetration of healthy bark occurred in 12 months. Spread of the fungus to adjacent roots at points of root contact was noted. Growth of mycelium on the bark surface was usually in advance of infection in the wood. Poria weiri mycelium continued to grow vigorously during the fall and winter months of the study period." (A)

612. Wallis, G. W., and G. Reynolds.  
1965. The initiation and spread of Poria weiri root rot of Douglas fir. Can J. Bot. 43(1):1-9.

"Reports...infection trials indicating that mycelium could invade roots of trees felled at least 12 months earlier, and the heartwood that had been buried for 12 months, and that Alnus rubra and Acer macrophyllum showed considerable resistance." (FA)

613. Wang, Yu-Min.  
1965. Use of a series of aerial photographs to estimate growth of trees and stands. M.F. thesis. Univ. B.C., Vancouver. 143 p.

"On the whole, methods of prediction of growth of stands by the use of a series of aerial photographs should be useful unless the stand is so densely stocked that it would affect the measurements of compilation height.

"Measurements of crown width were revealed to be fairly accurate. The minimum standard error of the mean

difference was  $\pm$  0.21 feet for Douglas fir when compared with he ground data, and the maximum error was  $\pm$  0.58 feet for alder. When comparisons were made in terms of mean errors, cottonwood showed the least accuracy (-1.3 feet) while a consistent mean error of zero was obtained for Douglas fir, cedar and hemlock.

"There was no consistent result which would give a clue to determine which species gives the best height estimates." (A)

614. Warrack, G. C.  
1956. The management of hardwood timber stands. Pac. Coast Hardwoods (July), p. 12-14; Dec., p. 10. Northwest Hardwood Assoc., Seattle, Wash.

Discusses hardwoods grown in British Columbia. Makes suggestions for management, planting, thinning, and harvesting of red alder. (CFH)

615. Warrack, G. C.  
1958. Thinning experiments in red alder. In Research review, p. 48-50. B.C. For. Serv., Victoria.

616. Warrack, G. C.  
1964. Thinning effects in red alder. 8 p. B.C. For. Serv., Res. Div., Victoria.

617. Warrack, George.

1949. Treatment of red alder in the coastal region of British Columbia. B.C. For. Serv. Res. Note 14, 7 p. Victoria, B.C.

"Preliminary results of a thinning study started in 1948 indicate that a suitable time for a heavy thinning of pure Alder stands on good sites would be between 15 and 20 years. This should assist in the production of a merchantable stand within a 30- to 40-year rotation. The occurrence of epicormic branches may be a factor in determining rotation and density requirements." (FA)

618. Washington State University,

Cooperative Extension Service.

[n.d.] Growing red alder for profit. 6 p. Wash. State Univ., Pullman.

619. Washington Woodland Council.

1964. Growing red alder for profit. Oreg. State Univ. Fed. Coop. Ext. Circ. 725, 2 p. Corvallis.

620. Wayman, M., C. B. Anderson, and W. H. Rapson.

1965. Peracetic acid bleaching of groundwood from nine Canadian wood species. Tappi 48(2):113-120.

"Promising results have been obtained with 6 Canadian hardwoods and 3 softwoods, the best with Populus trichocarpa and the poorest with Alnus rubra." (FA)

621. Weatherby, Hugh.

1949. The use of chemical weed killers. B.C. Lumberman 33(8):51-52.

"Several projects using chemical sprays to keep roads and power-line rights of way free of weeds and tree growth have been examined, and it was concluded that chemical sprays kill any Alder and Arbutus they hit. Conifers among the Alder were apparently unharmed. The cost is only about 30% of that of slashing. A power-line right of way, 68 miles long and 100 ft. wide, was sprayed in 24 days by a crew of 9 men, 3 tank trucks and a jeep. Bracken can be killed, but is not much affected by the spray used for killing Alder and other brush." (FA)

622. Webb, Warren L.

1972. A model of light and temperature controlled net photosynthetic rates for terrestrial plants. In Proceedings--Research on coniferous forest ecosystems--A symposium, p. 237-242. Jerry F. Franklin, L. J. Dempster, and Richard H. Waring, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"The model described represents net CO<sub>2</sub> exchange in a steady state as the difference of two empirical functions describing respectively photosynthesis (in terms of light energy and temperature) and respiration (in terms of temperature only). The six parameters of the model were evaluated the use of data for the CO<sub>2</sub> exchange of Alnus rubra seedlings, 1-2 years old, in a controlled environment. The behaviour of the model agreed with experimental results over a wide range of temperatures (0-50 deg C) and light-energy values. The maximum CO<sub>2</sub> uptake by light-saturated seedlings occurred at 23 deg C." (FA)

623. Webb, Warren L., Michael Newton, and Duane Starr.  
1974. Carbon dioxide exchange of Alnus rubra: A mathematical model. *Oecologia* 17(4):281-291.

"The CO<sub>2</sub> exchange response of plants to multiple environmental variables is often difficult to frame for purposes of comparison. In this paper, a nonlinear model relating CO<sub>2</sub> exchange to light and temperature is derived from experimental curves determined in other investigations. Parameter values, determined from a least-squares fit of the model to CO<sub>2</sub> exchange data, are useful for comparing responses to light and temperature in terms of seasonal phenology, population heterogeneity, or species variation.

"The model was fitted to CO<sub>2</sub> exchange data of a group of 40 Alnus rubra Bong. (red alder) seedlings for steady-state combinations of light and temperature. The average deviation of the data from the model was  $\pm$  6.7%. This steady-state expression satisfactorily predicted CO<sub>2</sub> exchange for dynamic conditions of light and temperature occurring in a diurnal cycle." (A)

624. Webb, Warren Lewis.  
1971. Photosynthetic response models for a terrestrial plant community. Ph. D. thesis. Oreg. State Univ., Corvallis. 88 p.

"Photosynthetic response to light and temperature was modeled using data from a small red alder (Alnus rubra B.) community growing in a controlled environment chamber linked to the computer. This new system controls air temperature, root temperature, and vapor pressure

over a wide range, and both light intensity and spectral quality are comparable with natural sunlight. Net photosynthetic rates are measured by continuously monitoring atmospheric CO<sub>2</sub> in the gas-tight environment chamber. Photosynthetic measurements were taken between 0.06 ly/min and 0.68 ly/min (total short-wave radiation) at temperatures from 6° to 30° C.

"A stepwise multiple linear regression analysis accounted for 98% of the variation in steady-state net photosynthesis using light and temperature plus two interaction terms as independent variables. Non-linear models were constructed based on the known light curve for photosynthesis of single plants. The weighted average deviation of the data from the best non-linear model was  $\pm$  3.7%. Extrapolation of predicted photosynthetic response appears reliable except for an inconsistency at light energies below 5% full sunlight for temperatures less than 6° C." (BI)

625. Wells, Frank L., Lloyd E. Herdle, and Alexander Walker, Jr.  
1969. Rapid sulfite pulping in concentrated sulfur dioxide solutions. *Tappi* (52)11:2136-2140.

"Using concentrated solutions of free sulfur dioxide at pressures higher than those normally used in sulfite pulping, bleachable sulfite pulps have been made in 2 hr or less from a variety of hardwoods and softwoods, including Douglas-fir [and red alder]. The addition of an alcohol or organic acid to the cooking liquor reduces the maximum pressure reached and improves yield and bleachability of the pulps. With appropriate adjustments in cooking conditions, pulps suitable for paper or for esterification can be made. In either case the pulps can be bleached by a simple sequence

without alkaline refinement. The very short cooking times required suggest that a continuous process for the manufacture of sulfite pulp could be developed." (A)

626. Wellwood, R. W.

1956. The manufacture and uses of hardwood in British Columbia. 4 p. Northwest Hardwoods Assoc., Seattle, Wash.

627. West Coast Lumberman.

1949. Alder for plastics. West Coast Lumberman 76(10):102.

628. Westcott, Cynthia.

1971. Plant disease handbook. 3d ed. 843 p. Van Nostrand Reinhold Co.: New York, Cincinnati, Toronto, London, Melbourne.

A comprehensive volume discussing plant diseases and their pathogens; illustrated; alphabetical listing of host plants and their diseases, easily cross-referenced to specific pathogens. Alder is classified by generic name only. Good general index. (CFH)

629. Western Forestry and Conservation Association.

1953. Reports of the Pacific Northwest Seeding and Planting Committee on various recommended reforestation practices and techniques. 69 p. West. For. and Conserv. Assoc., Portland, Oreg.

630. Western Society of Weed Science. 1969. Degradation of several herbicides in red alder forest floor material. Res. Prog. Rep. 1969:21-22.

"Analyses of herbicide residues in material from the forest floor under Alnus rubra showed that amitrole and 2,4-D were rapidly decomposed; picloram was the herbicide most resistant to degradation, and 2,4,5-T was of intermediate persistence. The higher the rate of decomposition of the herbicide, the lower the hazard of stream pollution." (FA)

631. Wetzel, G.

1927. Chromosomenzahlen bei den Fagales. Ber. Dtsch. Bot. Ges. 45(4):251-252.

632. Wetzel, G.

1928. Chromosomenstudien bei den Fagales. Ber. Dtsch. Bot. Ges. 46(3):212-214.

633. Wetzel, G.

1929. Chromosomenstudien bei den Fagales. Bot. Arch. 25:257-283.

634. White, Gordon.

1974. Industrial hardwood research in northern Alabama. J. Ala. Acad. Sci. 45(4):353-358.

635. Wickliff, Carlos.

1977. The effects of cadmium on the nitrogen fixation system in Alnus rubra. Ph. D. thesis. Oreg. State Univ., Corvallis. 242 p.

"Alnus rubra (Bong.) seedlings were grown in sand culture and irrigated with nutrient solution containing CdCl<sub>2</sub> ranging from 5 µg to 100 mg per liter. Treatment of A. rubra seedlings for 4 weeks with 50 and 100 mg CdCl<sub>2</sub> per liter of nitrogen-free nutrient solution decreased *in situ* nitrogenase activity 93 and 99%, respectively, when compared to controls. Nitrogen fixation was decreased 32 and 65% at CdCl<sub>2</sub> concentrations of 50 and 100 mg per liter, respectively. Growth was decreased to about the same extent as nitrogen fixation. Cadmium concentrations in the organs of A. rubra increased with increasing CdCl<sub>2</sub> concentrations in the nutrient solution and increasing duration of treatment.

"A. rubra seedlings without nodules were inoculated at the start of the experiment. The growth period prior to apparent nodulation increased from 5 to 8 weeks as the CdCl<sub>2</sub> concentration increased from 10 to 100 µg per liter of nitrogen-free nutrient solution. No detectable nitrogen fixation was observed at higher cadmium concentrations. Decreases in plant growth from CdCl<sub>2</sub> treatment were roughly parallel to decreases in nitrogen fixation.

"These results indicate that cadmium in nutrient media inhibits nitrogenase activity, and therefore nitrogen fixation in Alnus rubra. Growth, nodulation, and nitrate reductase activity were inhibited by the element. Observations of root and nodule cell ultrastructure suggest that cadmium exerts a portion of its effect by influencing the structure of organelles." (A)

636. Wicklow, Marcia C., Walter B.

Bollen, and William C. Denison.

1974. Comparison of soil microfungi in 40-year-old stands of pure alder, pure conifer, and alder-conifer mixtures. *Soil Biol. and Biochem.* 6(2):73-78.

"Samples were taken from the L, F, and All layers in three adjacent stands composed of (a) pure Alnus rubra, (b) a mixture of Picea sitchensis, Pseudotsuga menziesii, and Tsuga heterophylla, and (c) a mixture of alder and conifers, in the coastal fog belt of Oregon. The 92 species of microfungi isolated are tabulated, and their occurrence and frequency in species composition of the fungal populations was strongly correlated with the dominant vascular vegetation, and differed little between horizons within a stand. Stand (a) had a large number (16) of co-dominant fungus species, and Penicillium daleae, generally considered a rare species, reached a frequency of 83%. Stands (b) and (c) showed significantly fewer fungus species, and stand (c) was intermediate between the other two stands in terms of species composition." (FA)

637. Wicklow, Marcia Cope.

1972. A comparison of soil microfungi in forest stands of red alder, conifer, and alder-conifer mixtures. Ph. D. thesis. Oreg. State Univ., Corvallis. 64. p.

"The species composition of soil microbial populations in adjacent stands of red alder, conifers, and mixed alder conifer correlated strongly with the dominant vascular vegetation. A total of 92 species were isolated: 55 from the alder stand; 45 from the conifers; and 46 from the mixed alder-conifer,

with few species (16, 7, and 5 in the three plots, respectively) reaching average frequencies of 50% or higher. Penicillium nigricans, Aureobasidium pullulans, Cephalosporium curtipes, and Cladosporium herbarum were present with high frequency at all sites.

"There was little difference in species composition among soil horizons within a stand. Fungi which were dominant in one layer were dominant in the others.

"Three isolation techniques: dilution plates, soil plates, and immersion tubes, did not yield significant differences in species composition.

"In all three stands, numbers of species were greatest in February and lowest in June, following seasonal maxima and minima of soil moisture." (BI)

638. Wiley, Kenneth N.

1965. Effects of the October 12, 1962 windstorm on permanent growth plots in southwestern Washington. Weyerhaeuser For. Pap. 7, 13 p. Weyerhaeuser Co., Centralia, Wash.

"Two hundred nineteen permanent growth plots in Southwest Washington, primarily Douglas-fir and western hemlock 20 to 130 years of age, were examined. Nineteen had been destroyed and 74 were damaged. Damage was concentrated in the older age classes of both species. On the damaged plots, dominant and codominant trees accounted for 83 per cent of the mortality in terms of basal area but 40 percent of this mortality as in trees with root or stem rot." (A)

639. Williamson, Richard L.

1968. Productivity of red alder in western Oregon and Washington. In Biology of alder, p. 287-292. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Red alder in western Oregon and Washington grows rapidly when young and outproduces Douglas-fir up to ages 25-30 years on median sites of both species. Red alder readily responds to thinning. Its ability to add nitrogen to soil is important for site improvement over much of its natural range." (A)

640. Willis, J. C.

1966. A dictionary of the flowering plants and ferns. 7th ed. 42 p. Cambridge Univ. Press, Cambridge.

641. Wilson, Donald F., L. N. Johanson, and Bjorn F. Hruffiord.

1972. Methanol, ethanol, and acetone in kraft pulp mill condensate streams. Tappi 55(8):1244-1246.

"Methanol, ethanol, and acetone are three important water-soluble steam-volatile compounds found in kraft mill condensate streams. The extent of their formation is reported as a function of wood species pulped, based on laboratory digestion of

642. Winjum, Jack Keith.  
1969. Studies of the competitive performance of outplanted 2 + 0 Douglas fir (Pseudotsuga menziesii [Mirb.] Franco) through the first growing season. Ph. D. thesis. Univ. Mich., Ann Arbor. 130 p.
- "Pot studies were used to determine optimum environments for Douglas Fir seedling growth as regards light, moisture and rates of NPK application, and the effect of competition by Gaultheria shallon (which favoured Douglas Fir growth in terms of dry-weight gain) and Alnus rubra (which depressed growth). In field studies, however, when Douglas Fir was planted out in natural G. Shallon or A. rubra communities, both species reduced root and shoot growth of the Douglas Fir compared with controls." (FA)
643. Wise, Louise E., Evelyn K. Ratcliff, and B. L. Browning.  
1948. Determination of mannose. Mannans in hardwoods. Anal. Chem. 20(9):825-828.
- "The Hagglund-Bratt method for the determination of mannose and mannans in wood was modified and applied to 4 hardwoods (Oregon maple [Acer macrophyllum], Aspen [Populus tremuloides], Red Alder [Alnus rubra] and Querbracho Colorado [Schinopsis sp.]) all of which proved to contain small amounts of mannan. In at least one case (Aspen), mannose units were shown to be present in hardwood cellulose. Cotton linters, on hydrolysis, gave no mannose. The results are tabulated." (FA)
644. Wollum, A. G., II, and C. T. Youngberg.  
1964. The influence of nitrogen fixation by nonleguminous woody plants on the growth of pine seedlings. J. For. 62(5):316-321.
- "Nodulated seedlings of Ceanothus velutinus (a) and Alnus rubra (b) were grown in low-N-content soils (pumice and granitic respectively) in the greenhouse. After 9 months the seedling tops were removed at the ground line and Pinus radiata sown in the pots and also in pots of fresh soil that had been supplied with N at 0, 25, 50, 75, and 100 p.p.m. All treatments received 100 p.p.m. of P. After 12 months, the Pine seedlings were harvested, weighed, and analysed for N. The yield and N content of seedlings in (a) pots were comparable to those receiving 35 p.p.m. of added n, and those in (b) pots to 15 p.p.m. Another experiment was designed to investigate the effect of various litters on growth of P. radiata seedlings in a granitic soil. Douglas Fir litter at a rate of 250 g./2500 g. soil depressed the growth of P. radiata, whereas Alder improved it." (FA)
645. Woodworth, Robert H.  
1929. Cytological studies in the Betulaceae. II. Corylus and Alnus. Bot. Gaz. 88(4):383-399.
- "Corylus exhibits no polyploidy, all species and hybrids having the haploid number of 14 chromosomes. Throughout the genus there occurs a fusion of 1, 2, or 3 pairs of bivalent chromosomes, thus often causing the haploid number to appear to be less than 14. Natural hybrids are easily formed. These plants show some of the cytological peculiarities known to be due to heterozygosis. The fundamental number of chromosomes in Alnus is also 14, 2n and 4n species are

described. Alnus rugosa shown marked hybrid cytological characters and is considered heterozygous. It forms its seed apomictically. Alnus rugosa and A. glutinosa exhibit fusion of bivalent chromosomes. Cytomyxis and chromosome migration take place in certain species of Corylus and Alnus. Dysploidy may be due to unequal chromosome distribution, chromosome extrusion, or to cytomyxis and chromosome migration. A perinuclear zone occurs in the pollen mother cells." (BA)

646. Worthington, Norman P.  
1957. Silvical characteristics of red alder. Pac. Northwest For. and Range Exp. Stn. Silvical Ser. 1, 15 p. Portland, Oreg.

"The first of a 'silvical characteristics' series to be produced by this Station on the same lines as those being published by other Federal Stations. These compilations aim at giving information on habitat conditions, life history, including growth and yield, injuries, races and hybrids, and any special features, preliminary to eventual publication in book form." (FA)

647. Worthington, Norman P.  
1963. Thirteen years of thinning in a Douglas-fir woodland. USDA For. Ser. Res. Note PNW-8, 4 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Yields over the past 13 years from a typical 57-year small woodland in Washington (consisting of 2/3 Douglas Fir with Western Redcedar, Western Hemlock and Red Alder) are analysed to demonstrate that management can produce an annual income from thinnings while maintaining or increasing production." (FA)

648. Worthington, Norman P., Floyd A. Johnson, George R. Staebler, and William J. Lloyd.  
1960. Normal yield tables for red alder. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Pap. 36, 32 p. Portland, Oreg.

"Computed from data from 428 Alnus rubra sample plots in pure stands aged 10-80 years in N.W. Oregon, W. Washington, and S. British Columbia. Methods of preparation are briefly described." (FA)

649. Worthington, Norman P., Robert H. Ruth, and Elmer E. Matson.  
1962. Red alder, its management and utilization. U.S. Dep. Agric. Misc. Publ. 881, 44 p. Washington, D.C.

Covers silvicultural characteristics and increment as well as management and utilization. (CFH)

650. Wright, Ernest.  
1954. A preliminary study of the deterioration of alder and Douglas-fir chips in outdoor piles. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 99, 5 p. Portland, Oreg.

"In a pilot test, lasting 1 year, of a pile containing 2/3 Alder and 1/3 Douglas, deterioration of Alder chips was slowed down without increasing the decay in Douglas Fir for the test period. A pile containing 90% Douglas Fir and 10% Alder showed no decay during the test. This test is not considered conclusive." (FA)

651. Wu, Chih Fae.

1977. The chromophoric behavior of Norway spruce, western hemlock and red alder thermomechanical pulps. M.S. thesis. Univ. Wash., Seattle. 57 p.

Pulp produced by thermomechanically processing wood with high temperature pressurized steam is discolored because of the extractive and lignin components of wood. Brightness varies with species and with steaming temperature. High temperatures usually result in darker pulp. Under the same conditions, Norway spruce is brighter than either western hemlock or red alder. Sodium sulfite pretreatment can increase the brightness of thermomechanically produced pulp, largely eliminating the effect of extractives. It demonstrates a potential for producing pulp by thermomechanically processing wood especially that of hardwood species. (CFH)

652. Yarwood, C. E., and M. W. Gardner.

1972. Powdery mildews favored by agriculture. (Abstr.) Phytopathology 62(7):799.

"Certain host/pathogen associations in the Erysiphaceae have been found only in habitats disturbed by man, and not where the hosts occur naturally: Erysiphe cichoracearum on 11 species of Eucalyptus; E. polygoni, Microsphaera alni, and Phyllactinia corylea on 30 species of Quercus and Lithocarpus; and others. Only three host/pathogen associations, including M. alni on Alnus oregonia (A. rubra) appeared to be as abundant on undisturbed wild plants as on those influenced by man. Tillage and pruning were shown in this study to favour disease." (FA)

653. Yarwood, C. E., and M. W. Gardner.

1972. Powdery mildews favored by man. Plant Dis. Rep. 56(10):852-855.

"The following Erysiphaceae were abundant in cultivated areas, but conspicuously absent where the hosts occurred naturally in areas relatively undisturbed by man: Erysiphe cichoracearum on Baccharis pilularis var. consanguinea, Erysiphe polygoni on Eschscholtzia californica, Sphaerotheca fuliginea on Navarretia squarrosa, S. fuliginea on Prunella vulgaris, and S. lanestris, E. trina, Microsphaera alni and Phyllactinia corylea on 30 species of Lithocarpus and Quercus. Most of some 1400 collections of Erysiphaceae on some 536 host species from 1934 to 1972 have been on cultivated plants, or in botanic gardens, greenhouses, parks, campuses, and roadsides, and it is not known whether the mildew also occurs in the native habitat of the host. Only three host: pathogen associations (M. alni on Alnus oregonia, P. corylea on Diplacus aurantiacus, and E. cichoracearum on Myosotis sylvatica) appeared to be as abundant on undisturbed wild plants as on those manipulated by man. A positive correlation of leaf size with susceptibility of Quercus agrifolia to E. trina and of Q. ilex to S. lanestris was established. The relative role of tillage, fertilization, watering, pruning, greenhouse culture, or some unknown factor in favoring mildews is unclear. Of these, only tillage and pruning have been demonstrated to favor disease in this study." (A)

654. Yoho, James G., Daniel E. Chappelle, and Dennis L. Schweitzer. 1969. The economics of converting red alder to Douglas-fir. USDA For. Serv. Res. Pap. PNW-88, 31 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"This study defines those conditions where it is more profitable to replace red alder stands with Douglas-fir than to manage for red alder. Under most of the circumstances analyzed, red alder stands should be immediately converted. In order of importance, the critical variables in this decision were found to be the discount rate, site productivity, expected stumpage prices, the present age of the existing red alder stand, costs of conversion, and annual management costs. Sensitivity analyses suggest how these variables influence the conversion decision." (A)

655. Yoho, James G., Daniel E. Chappelle, and Dennis L. Schweitzer. 1969. The marketing of red alder pulpwood and saw logs. USDA For. Serv. Res. Note PNW-96, 7 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"In the Pacific Northwest, red alder has invaded many cutover areas which once supported Douglas-fir. As the supply of red alder increased, more uses were found and red alder became more valuable. This Note measures the present red alder resource and summarizes its production, marketing, and future prospects." (A)

656. Zabka, Josef. 1942. Taxonomické poznámky o olší a jejím geografickém rozšírení. [Taxonomic notes on alder and its geographic distribution.]. Lesn. Pr. 21(1):10-20. [In Czech., German summary.]

"Two subgenera of Alnus are distinguished: Alnobetula, with 1 species, A. virdis; and Gymnothrysus, with 8 species, A. cordata, A. subcordata, A. japonica, A. incana, A. rubra, A. tenuifolia, A. rugososa, and A. glutinosa." (FA)

657. Zach, Lawrence W., Don Bauer, and Hal Goodyear. 1943. Practical application of plant hormones in forest-tree propagation. J. For. 41(3):214.

"Results from preliminary experiments show that: (a) for extensive field planting, cuttings treated with indolebutyric acid are not practicable in the propagating of Douglas Fir, Port Orford Cedar, Western White Pine, Western Weeping Hemlock, Red Alder, and Shipmast Locust; (b) seedlings (2-0 and 1-0 stock) of Douglas-fir, Port Orford Cedar and Ponderosa Pine, and of Western White Pine (2-0 stock only) do not react significantly to treatment with indolebutyric acid; (c) seeds of Sugar Pine and Port Orford Cedar treated with indolebutyric acid appear to give positive results, those of Western White Pine negative results, while those of Douglas Fir show no significant effect. It is suggested that the apparent ineffectiveness of hormone treatment may be due to temperature conditions." (FA)

658. Zavitkovski, J., and M. Newton. 1971. Litterfall and litter accumulation in red alder stands in western Oregon. *Plant and Soil* 35(2):257-268.

"Litter accumulation in 2- to 33-year-old Alnus rubra communities in the Coast Range area of W. Oregon is greater than that reported for any other plant community of the temperate regions. Litter production is also unusually high in communities of other N-fixers, such as Ceanothus velutinus. This character suggests that the ability of such species to produce large quantities of N-rich litter, even in an unfavourable environment, is related to their ability to fix N. Litter accumulates rapidly on the ground during the first five years after establishment of A. rubra, but equilibrium is reached at age 6, and is maintained after several decades. During this time, the decomposition of litter equals the annual litter fall. In 50 years, cumulative litter fall reaches >300 metric tons/ha, most of which is decomposed and incorporated into the mineral soil. Favourable physical, chemical, and nutritional soil conditions are created by Alder for the development of the climax vegetation." (FA)

659. Zavitkovski, J., and Michael Newton. 1968. Effect of organic matter and combined nitrogen on nodulation and nitrogen fixation in red alder. In *Biology of alder*, p. 209-223. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

"Nodulation and growth in dry weight of red alder plants were influenced favorably by increasing levels of total soil nitrogen (TSN). Few but large nodules developed in soils with low TSN; in soils with high TSN, nodules were small but more numerous. Accretions of nitrogen to the systems and efficiency of nitrogen fixation peaked between 0.03 and 0.05 percent TSN. Nodulation was adversely affected by urea-nitrogen, but additions of 15-30 ppm of nitrate-nitrogen depressed the nodulation. Rates of nitrogen fixation of over 300 kg/ha year, determined under red alder stands 2-14 years old, were substantiated by greenhouse experiments. Based on efficiency of nitrogen fixation of about 5.4 mg N/day g nodule, dry weight, rate of fixation could reach 140 kg/ha year of nitrogen in a 7-year-old alder stand, and up to 209 kg/ha year in a 30-year-old stand. Based on average accretion of 220 mg of nitrogen per kilogram of soil, nitrogen fixation could approach 100 kg/ha during the first year in the field." (A)

660. Zavitkovski, J., and R. D. Stevens.  
1972. Primary productivity of red  
alder ecosystems. *Ecology*  
53(2):235-242.

"Fifty red alder communities from 1 to 65 years old were studied in western Oregon. Highly significant correlations were found between an index of volume and dry weights of whole trees, individual stems, crowns, tops, and roots. Correlations of dry weight with other independent variables (age, dbh, height) were variable and strongly curvilinear. Ratios of crown to stem in dominant trees were higher than those of suppressed or intermediate trees. Biomass of aboveground parts increased rapidly during the first 20 years and reached about 240 mt/ha by the age of 33 years. Net primary productivity during the years of maximum growth (between 10 and 15 years) averaged 26 mg/ha per year. Net assimilation rates ranged from 2.58 to 4.33 mt/mt per year. To produce best yields, red alder stands should be harvested before 20 years of age." (A)

661. Zavitkovski, Jaroslav, and Michael Newton.

1967. The role of snowbrush (*Ceanothus velutinus* Dougl.) and red alder (*Alnus rubra* Bong.), in forest regeneration in the Pacific Northwest. *Int. Union For. Res. Organ. 14th Congr. Proc. Part II (Sect. 21)*, p. 429-440. [Munich.]

"Both species are, because of their litter production, important pioneer species and soil builders in the early stages of succession on infertile soils. Their role as nurse crops is, however, of doubtful value and their net effect on conifers is more harmful than beneficial. Snowbrush may decrease the survival of natural or planted conifer seedlings, development of which may be retarded by 5-15 years. The suppressive potential of Red Alder is even more pronounced, and only the most tolerant species may be able to survive under heavy stands." (FA)

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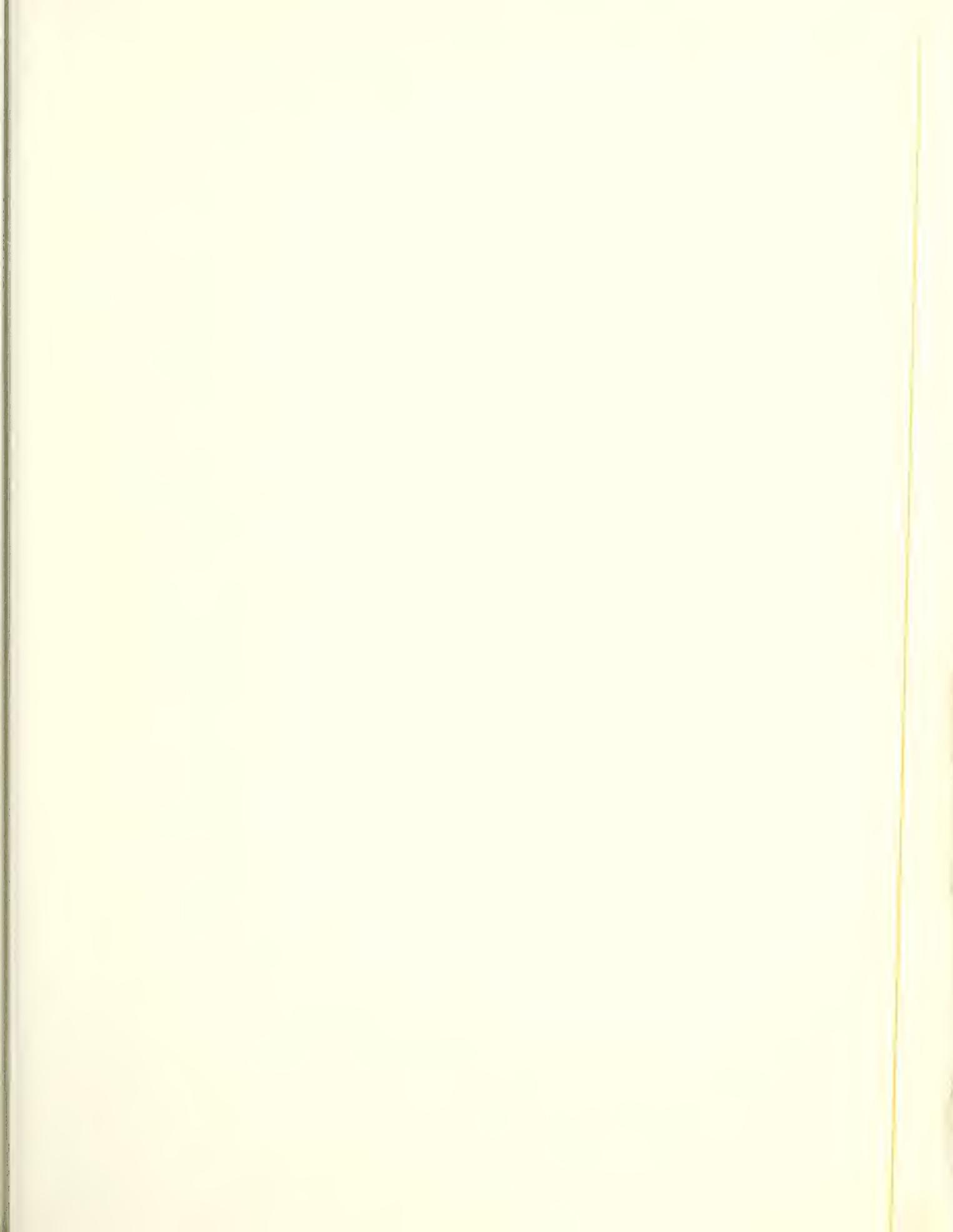
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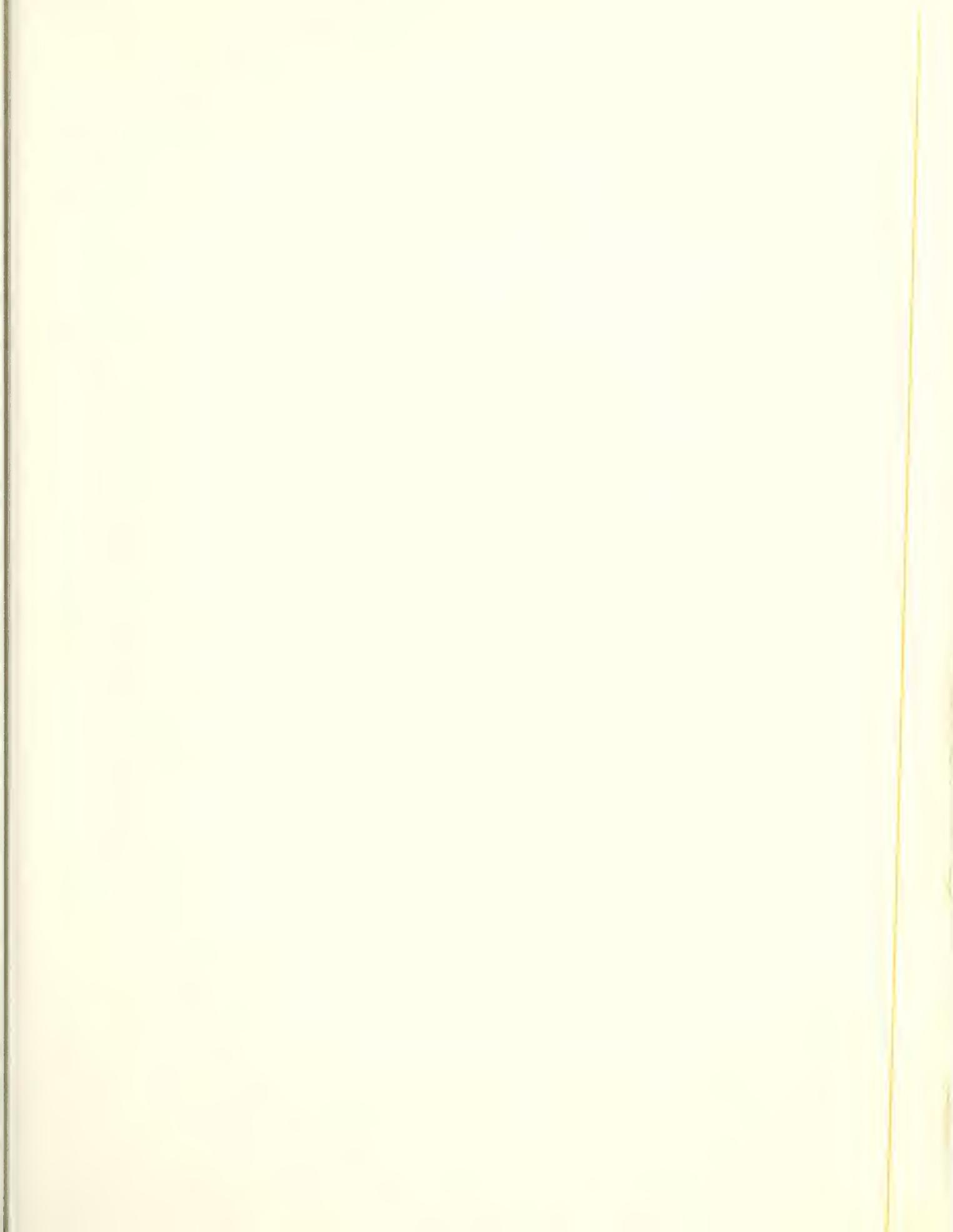
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# Methods and Materials for Locating and Studying Spotted Owls

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## Abstract

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Nocturnal calling surveys are the most effective and most frequently used technique for locating spotted owls. Roosts and general nest locations may be located during the day by calling in suspected roost or nest areas. Specific nest trees are located by: (1) baiting with a live mouse to induce owls to visit the nest, (2) calling in suspected nest areas to stimulate the female to call or fly from the nest, or (3) observing adults during prenesting displays. An effective technique for climbing large nest trees is to rig the tree with a climbing rope. Mechanical climbing aids are then used to ascend the rope. The principal method used to determine the diet is identification and enumeration of prey in regurgitated pellets. The most effective method of trapping spotted owls is with a noose pole. Other trapping methods include mist nets, bal-chatri traps, bow nets, and dip nets. Radio transmitters for long-term radiotelemetry studies are usually attached with a backpack harness; the antenna should be reinforced to keep it from crimping or breaking.

Keywords: Wildlife surveys, birds, owls (spotted).

## Introduction

In recent years, a variety of methods for locating and studying spotted owls (*Strix occidentalis*) have been developed. Many of these techniques have spread by word-of-mouth among biologists but have not been well described in the literature. This manual describes the techniques that I (and other biologists) have found most effective for locating and studying spotted owls. I have written the manual with the inexperienced observer in mind, but it should be useful to experienced owl biologists as well.

## Locating Spotted Owls

The most efficient way to locate spotted owls is to imitate their calls. Upon hearing a suspected intruder within their territories at night, most spotted owls respond by approaching the intruder and calling. Spotted owls are normally nocturnal but will also call during the day if vocally stimulated. During the day, however, response is usually limited to the immediate vicinity of the roost area. In contrast, owls will often fly long distances at night to confront an intruder. Most investigators use nocturnal calling surveys to determine the general location of a pair of owls; daytime calling surveys are used to locate nest and roost areas.

Spotted owl calls may be imitated vocally or played back on a tape recorder. Both methods are effective, but vocal imitations allow the investigator to dispense with such problems as malfunctioning tape recorders, poor recordings, broken tapes, and extra weight. If a tape recorder is used, an amplifier is generally unnecessary as long as the recorder has a good speaker and power output of 5 watts or more. Tape recordings of spotted owl calls are available from the Regional Offices of the USDA Forest Service in Oregon and California and from the Oregon State Office of the Bureau of Land Management, U.S. Department of the Interior.

The call most frequently used for locating spotted owls is a series of four hoots (*hoo—hoo - hoo—hoo!*) (Bent 1938, Forsman 1976, Ligon 1926). Spotted owls have a variety of other calls that can be used for survey work (Forsman 1976), but for most purposes, the four-note hooting series is adequate. Hooting calls should be repeated at intervals of 10 to 30 seconds. Some investigators insert an occasional run-on series of several calls in rapid succession.

## Nocturnal Calling Surveys

The sampling approach used for surveying spotted owls depends on whether a complete count or an index of density is required. To obtain a complete count of all pairs in a given area, I select a network of roads and trails that allows complete coverage of the area and then drive or walk the roads and trails at night, stopping to imitate spotted owl calls at frequent intervals. "Complete coverage" of the area means that imitated calls can be heard from every spot within the survey area at least once during the survey. When working alone, I usually call from one spot for several minutes, then drive 0.3 to 0.8 km (0.2 to 0.5 mi) before stopping to call again. When working with another caller I use the "leapfrog" method; one caller proceeds on foot along a road while the other drives ahead about 0.8 km (0.5 mi), parks the vehicle, and proceeds on foot. Both callers walk in the same direction along the road, imitating spotted owl calls. On reaching the vehicle, the caller who was dropped off first drives it past the other caller about 0.8 km, parks, and again proceeds on foot. By continuously repeating this procedure, two people can cover a large area relatively fast.

Regardless of which method is used, some pairs will almost always be overlooked during a single pass through an area. For an accurate estimate of the number and distribution of pairs, therefore, it is usually necessary to survey an area several times. If a survey is repeated two or three times in one summer without revealing any additional pairs, it is usually safe to conclude that all pairs in the survey area have been located. For maximum accuracy, however, surveys should be repeated at least two summers in a row.

If time does not permit a complete survey, several methods can be used to determine the relative abundance of owls in different areas or cover types. One approach is to compare the average number of owls responding per unit length of road transect (Forsman and others 1977, Marcot and Gardetto 1980). Another approach is to compare the average number of owls responding per calling point or per unit time (Marcot and Gardetto 1980). Calling stations for the latter methods should be at least 0.8 km (0.5 mi) apart to reduce the chance of individual owls following the investigator

from one station to the next. If it is obvious that an owl has followed the investigator, that owl should not be counted again.

Calling surveys should be conducted between March and September. In winter, spotted owls become less vocal and are more difficult to locate. When possible, calling surveys should be conducted during fair weather. During stormy or windy weather, owls are usually more difficult to hear, and may become less responsive. The latter possibility has not been tested statistically, but many investigators with whom I have spoken agree that response rates generally decline during stormy weather. Most investigators also agree that response rates generally decline in years when the proportion of nonnesting pairs is high. This factor is difficult to compensate for except by repeating surveys in both good and poor nesting years.

During calling surveys, it frequently becomes necessary to interpret situations in which only one owl responds in a given area. In most cases, the investigator is interested in the number of resident pairs of owls, and the location of only one owl results in ambiguity about the presence of a pair. The only way to resolve this dilemma is to survey the area several times each year for at least 2 years in a row. This allows for the possibility that one member of a pair has died and will soon be replaced. If time is not available to document the existence of a pair, I recommend assuming that a pair is present in areas where single owls respond. In my experience, this assumption is correct most of the time. Marcot and Gardetto (1980) suggested that the types of calls given by spotted owls could be used to distinguish between paired and unpaired individuals and that it could be assumed that an owl was paired if it did not stop calling when spotted owl calls were imitated nearby; these assumptions have not been verified.

## Locating Roosts

During the day, spotted owls retire to a secluded roost on a limb in a tree. Ledges in caves are also used as roosts in the Southwestern United States and in Mexico (Ligon 1926). To locate roosts, most investigators imitate spotted owl calls in suspected roost areas during the day until a response is elicited. The investigator then homes in on the owl. When the investigator is unfamiliar with the habits of a particular pair, the usual procedure is to expand the search for roosts outward from the area where owls responded at night. To conduct a thorough search for roosts, the investigator must systematically walk and call each drainage in an area in such a way as to be heard in all potential roost areas; calling from roads is rarely adequate because many roosts are located so far from roads that the owls cannot be detected.

If the objective is to locate as many roosts as possible, the investigator should look for signs of roosting under adjacent trees in each area where owls are found roosting. Indications that a tree has been used for roosting include the presence of white fecal material, regurgitated pellets, or molted feathers under the tree.

## Locating Nests

Spotted owls lay eggs between March 1 and April 10; incubation lasts  $30 \pm 2$  days and is performed entirely by the female. The young remain in the nest for about 34 days, leaving the nest in May or early June (Bent 1938, Forsman 1976). Attempts to locate nests, therefore, should be conducted between mid-March and early June.

In the Pacific Northwest, spotted owls nest almost exclusively in cavities or platforms in conifers (Forsman 1976, Forsman and others 1984). Nests in caves, potholes in cliffs, and cavities in hardwood trees have been observed in southern California and in the Southwest (Dickey 1914, Dunn 1901, Ligon 1926, Peyton 1909) but are rare in Oregon and Washington. Cavity nests in Oregon and Washington are most commonly located in living old-growth conifers with broken tops; nests in snags are relatively uncommon. Regardless of whether the tree is alive or dead, cavity nests are usually located inside the hollow top of the broken bole (fig. 1). Less frequently,

cavity nests are located in the midbole region in holes created when large limbs rip loose from the trunk. Old-growth nest trees with broken tops are usually characterized by secondary tops (limbs that grow upward to form one or more new tops after the original top breaks off) (fig. 1).

Platform nests used by spotted owls include stick structures constructed by other animals (hawks and woodrats, for example) and natural accumulations of debris on top of limbs (Bendire 1882, Forsman 1976, Gould 1977, Ligon 1926). Platforms selected for nesting are frequently located in dense clusters of deformed limbs caused by dwarf mistletoe (*Arceuthobium* spp.) infections (Forsman 1976, Ligon 1926). Although Bendire (1882) suggested that a pair of spotted owls constructed their own nest, I believe he was mistaken; I have never seen any evidence that spotted owls build their own nests.

During the nesting period, male spotted owls usually roost near their nests during the day while females incubate and brood the young. The key to locating a nest, therefore, is to first locate the male in his day roost. When the male is located, an effective method of locating the nest is to tether a live mouse on the ground in front of the owl, walk away a short distance, and observe the owl's behavior. If the owl is nesting, it will usually capture the mouse and carry it directly to the nest. Transfer of the mouse to the female may occur at the nest or on a limb near the nest. In contrast to nesting owls, nonnesting males (or females) will usually eat the mouse. A problem with this method of nest location is that nesting males will occasionally eat the mouse instead of taking it to the nest. For this reason, the baiting procedure should be repeated on at least two days before conclusions about nesting status are drawn. The baiting technique is also effective for locating owlets after they leave the nest; adults will usually carry freshly killed prey to their young if the young are roosting nearby.



Figure 1.—A typical spotted owl nest cavity in the broken top of an old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Note the large limbs that have grown upward to form secondary tops after the original top broke off.

## Climbing Nest Trees

The mouse tether I use for baiting spotted owls consists of a piece of braided stainless steel fishing leader 25 cm (10 inches) long with a small safety pin attached to one end and a stiff piece of clothes hanger wire attached to the other (fig. 2). The clothes hanger wire is pushed into the ground to anchor the tether. The safety pin is inserted through the skin on the nape of the mouse's neck so the owl can easily pull the mouse loose from the tether. While tethering the mouse, the investigator should draw the owl's attention to it by squeaking like a small mammal in distress.



Figure 2.—A mouse tether used for feeding live mice to spotted owls.

Another method of locating spotted owl nests is to locate a roosting male during the nesting season and then imitate spotted owl calls in the area where the male is roosting. If the nest is nearby, the stimulus of a suspected intruder will frequently cause the female to call from the nest or to leave the nest to challenge the intruder; in either case the nest will be revealed. One shortcoming of this method is that some females will not leave the nest or call despite persistent vocal stimulation. Another shortcoming of the vocal stimulation method is that it involves considerable harassment of nesting females; this method should, therefore, be used only as a last resort.

A third method of locating nests is to observe the behavior of paired adults during the period of nest selection (March to early April). For 2 to 6 weeks before the eggs are laid, most nesting pairs roost near their traditional nest sites. During the last 2 to 3 weeks before nesting begins, these pairs copulate and display near the nest each evening. Nest locations can be determined during the latter period by locating the owls during the day and then observing their behavior at dusk. Copulation usually occurs at dusk and is followed by a display in which one or both adults fly to a perch near the nest and give the nest call—a series of evenly spaced hooting notes that may continue almost nonstop for several minutes (Forsman 1976). Females often enter the nest during this display.

After the young fledge, nests become difficult to locate; however, owlets cannot fly well for 2 to 3 weeks after leaving the nest and generally remain nearby. The location of recently fledged young is, therefore, a good indication of the general nest location. Even after they become more mobile in July and August, most owlets continue to roost within several hundred meters of the nest during the day; however, occasional exceptions to this pattern of behavior make it unwise to use the location of owlets to infer where the nest is located after the young have been out of the nest more than about 2 weeks.

Because individual spotted owls may not nest every year, it may be necessary to wait a year or more before nests of specific pairs can be located. The only alternative is to infer from the behavior of the owls where the nest is located. Most nonnesting pairs frequently roost near their traditional nest sites during the spring and summer; a concentration of heavily used roosts may, therefore, indicate the general nest location. There are, however, occasional exceptions. For this reason, inferences about nest locations based solely on the roosting behavior of nonnesting pairs should be avoided.

Small nest trees can usually be climbed with conventional tree climbing spurs and a flip rope. An easier way to reach nests in large, old-growth conifers, however, is to rig the tree with a climbing rope, which can then be ascended with Jumars or one of the other ascending devices used by mountain climbers.<sup>1/</sup> To rig nest trees, I use an archery bow equipped with a fishing spool to shoot a light line over the base of a strong limb near the nest. This line is then used to pull up a strong nylon cord (for example, parachute cord), which is used to pull up the climbing rope. It is sometimes necessary to climb an adjacent understory tree to get an unobstructed shot at a limb near the nest. The knot connecting the nylon cord and climbing rope should be wrapped with tape to keep it from snagging as it passes over the support limb. If nest trees are to be climbed more than once they can be left permanently rigged with a piece of nylon cord. Goggles or a face mask should be worn when nest trees are climbed because spotted owls often aggressively defend their nests.

<sup>1/</sup> The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

## Determination of the Diet

The usual method used to determine the diet of spotted owls is to examine the contents of their pellets (a pellet is a regurgitated mass of indigestible prey remains). Prey in pellets are identified and enumerated based on the morphological characteristics and number of skulls, mandibles, leg bones, wings, and so forth, that are present. Prey biomass is estimated by multiplying the number of individuals of each species consumed by the mean weight of the species. Some problems associated with dietary analyses based on pellet contents are: (1) Soft-bodied insects tend to be underestimated because their remains are almost entirely digested; and (2) the remains of large mammals or birds may appear in several pellets, either because the animal was too large to eat in one meal or because several owls (for example, adults and their young) fed on the same animal. One reviewer suggested that enumeration of vertebrate prey in pellets should be based only on the number of skulls present, thereby avoiding the possibility of counting large prey more than once. I disagree with this approach mainly because it may result in an underestimate of large prey in the diet; this inadequacy and other inadequacies with the skull-only approach to pellet analysis have been noted by Marti (1974), Mikkola (1970), and Southern (1954). A less conservative approach is to combine all pellets collected from a given roost area at each visit and to enumerate the prey based on the skeletal parts that generate the highest count for each species in the sample. If several roosts are used by the same owl(s) during the period of pellet collection, pellets from all the roosts should be combined for analysis. In many instances, a group of pellets collected from a roost will contain old, weathered pellets as well as more recent pellets. These different pellet "age" groups can be analyzed separately because there is no danger that the remains of a single prey animal will occur in both old and recent pellets.

Another method of collecting data on the diet of spotted owls is to observe the owls during the day to see if they have prey cached nearby. Spotted owls commonly cache uneaten prey on limbs or on the ground near their roosts (Forsman 1976, Huey 1913). The main drawback to this method is that large prey are often cached and eaten in several meals, whereas small prey such as mice are usually eaten in one meal. As a result, analyses of the diet based on cached prey tend to be biased in favor of large prey.

## Trapping Spotted Owls

Spotted owls are relatively easy to capture during the day. A variety of trapping techniques are available and may be used interchangeably, depending on the preference of the investigator.

The most efficient method for trapping spotted owls is a noose pole. Materials needed to construct a noose pole include a very stiff surf casting rod about 3.4 m (11 ft) long, a fly fishing reel, a spool of 18-kg (40-lb) test monofilament fishing line (a gray color is best), a piece of soft copper wire, some scraps of cork or hard rubber, and two split rings about 3 mm (3/16 inch) in diameter. Figure 3 illustrates the construction of the noose pole.

To noose an owl, I use a mouse on a tether to first lure the owl to a perch near the ground. Then, while an assistant continues to distract the owl with the live

mouse, I slip the noose over the owl's head and gently pull the noose tight. When the noose is pulled tight it pulls out of the slits in the cork or rubber noose supports (fig. 3). The owl is then lowered to the ground as quickly as possible and restrained. The two split rings, which are tied about 95 cm (3-3/4 inches) apart on the monofilament line, act as a stop mechanism to keep the noose from choking the owl (fig. 3). The fishing reel is used to keep the monofilament line neatly coiled when it is not in use.

Aside from its efficiency, the greatest advantage of the noose pole method is that spotted owls do not learn to associate the tethered mouse with the noose, and thus do not become trap shy. The noose pole method does not harm the owl in any way, as long as the owl is not left hanging from the noose.

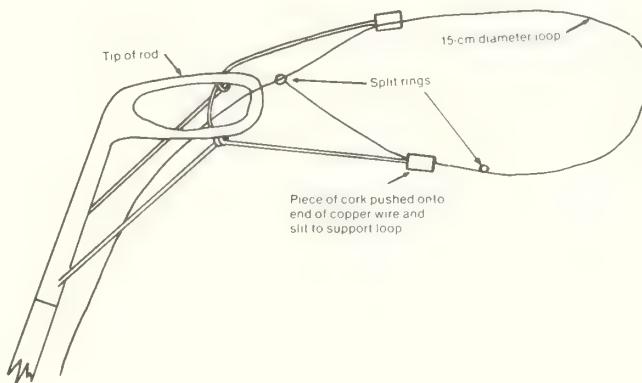


Figure 3.—A noose pole used to capture spotted owls.

## Radiotelemetry and Visual Markers

Another method of trapping spotted owls is to lure them into a mist net with a live mouse for bait. A standard four-panel mist net with 10-cm (4-inch) mesh is used; the net should be relatively short (5-6 m; 15-20 ft), as longer nets are difficult to set up in dense forests. If the owl is roosting on a hillside, the net should be set just downhill from the owl and at right angles to the slope. A live mouse is then tethered to the ground about 1 m (3 ft) uphill from the net, between the owl and the net. As soon as the investigator walks away a few paces, the owl will usually fly downhill, grab the mouse, and fly into the net (spotted owls almost always fly downhill after capturing prey on the ground). The net is placed downhill from the owl because even if the owl bounces back out of the net it will often continue to try to escape downhill, and will reenter the net.

If the owl is roosting on level terrain, the mouse should be tethered behind the net so that the owl hits the net while flying toward the mouse. If there are no suitable places to set the net in the immediate roost area, the investigator can frequently lure the owl to a new perch by walking away a short distance and making squeaking sounds from behind a tree. Usually, the owl will fly over to explore the source of the sound and can be trapped in the new location.

Other types of traps used to capture spotted owls include bow nets (Beebe and Webster 1964), bal-chatri traps (Berger and Hamerstrom 1962), and dip nets. One reviewer suggested that bal-chatri traps were just as effective as the mist net method and were easier to use. I have had good success using bow nets to trap spotted owls except that occasional individuals flew in and out of the trap so quickly they avoided capture.

To attach radio transmitters to spotted owls, I use a backpack harness like that described by Dunstan (1972). The harness is made from tubular teflon ribbon that is 6 mm (1/4 inch) wide (Bally Ribbon Mills, Bally, PA 19503; see footnote 1). To make the transmitter harness, cut two pieces of teflon ribbon about 35 cm (14 inches) long and attach them to the bottom of the transmitter with a strong layer of acrylic (fig. 4). These two straps are then looped around the owl's body in front of and behind the wing and sewn together over the breast (fig. 5). The loops are held together over the breast by a short strap, which is also used to take up slack in the body loops; the harness should be snug enough to keep the transmitter from flopping around, but not so tight that it constricts breathing or movement. I usually sew the front body loop before going to the field so that it can be slipped over the head of the owl (fig. 4). Then, all that is necessary in the field is to sew the ends of the posterior body loop together and connect the two loops with the breast strap. The circumference of the pre-sewn front loop should be 23 to 24 cm (9.5 inches) for spotted owls.

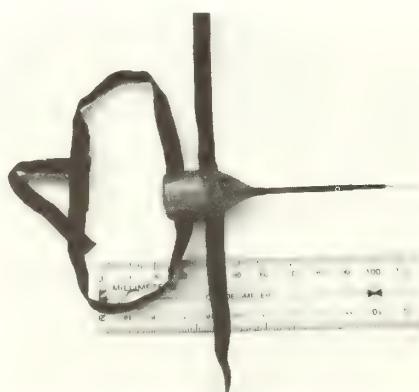


Figure 4.—A radio transmitter ready to install on a spotted owl. The antenna has been reinforced around the base with heat-shrink tubing and the battery and transmitter have been encapsulated in waterproof acrylic. The front loop of the harness has been pre-sewn so that it can be slipped over the head of the owl. The short strap attached to the front loop is used to connect the front and rear loops together. This transmitter package weighed 21 grams.



Figure 5.—Attaching a transmitter to a spotted owl. The piece of nylon material under the harness straps was used to keep feathers out of the way while the loops were sewn together.

Transmitter antennas should be reinforced at the base so they do not become crimped or broken. Dunstan (1972) used a small spring to reinforce antennas; another alternative is to encapsulate the base of the antenna in two or three layers of heat-shrink tubing, as shown in figure 4.

To track radio-tagged owls at night, I use a hand-held yagi antenna and a whip antenna mounted on a vehicle. The whip antenna is used to determine when an owl is within receiving distance; the hand-held antenna is used to triangulate the position of the owl or to home in on the owl. More sophisticated receiving systems such as fixed antennas and null-peak antennas are not particularly effective or practical in the rugged terrain and dense forests occupied by spotted owls.

Before a radiotelemetry study is conducted, it is necessary to obtain a radio frequency clearance from the U.S. Federal Communications Commission, Washington, D.C. In addition, all studies that involve the marking of migratory birds must be approved by the U.S. Department of the Interior Fish and Wildlife Service Bird Banding Office, Patuxent, Maryland, and the State wildlife agency in the State where the research is conducted. The current policy of the Bird Banding Office is that transmitters used on birds should weigh no more than 3 percent of body weight. To be within the 3-percent limit, transmitters used on spotted owls should not exceed 20 g (0.71 oz) for males and 23 g (0.81 oz.) for females. If possible, transmitters should be removed after a study is completed.

## **Barred Owls and Spotted Owls**

As far as I have been able to determine, leg banding is the only method other than radiotelemetry that has been used to mark spotted owls. Leg bands are of limited value as visual markers because they become obscured by the feathers on the leg. Patagial wing markers and feather imping (grafting a distinctively marked feather into the shaft of a primary or rectrix) (Schemnitz 1980) have not been tried on spotted owls, but they should be effective marking techniques.

In recent years, the barred owl (*Strix varia*) has begun to invade the range of the spotted owl (Taylor and Forsman 1976). Because barred owls and spotted owls are similar in appearance and sound somewhat alike, investigators should become familiar with the calls and appearance of both species. In addition to differences in their plumage and calls, spotted and barred owls behave differently when approached by humans during the day; barred owls usually flee when approached closely, whereas spotted owls show little sign of fear.

Sightings of barred owls in Oregon and California should be carefully documented and reported so that investigators will be able to track the range expansion of the species in the future. The effect of the barred owl invasion on spotted owl populations is unknown.

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## Literature Cited

- Beebe, F. L.; Webster, H. M. North American falconry and hunting hawks. Denver, CO: World Press, Inc.; 1964. 315 p.
- Bendire, C. E. The spotted owl. Ornithologist and Oologist. 7: 99; 1882.
- Bent, A. C. Life histories of North American birds of prey. Part 2. Bull. 170. Washington, DC: U.S. National Museum; 1938. 482 p.
- Berger, D. D.; Hamerstrom, F. Protecting a trapping station from raptor predation. J. Wildl. Manage. 26: 203-206; 1962.
- Dickey, D. R. The nesting of the spotted owl. Condor. 16: 193-202; 1914.
- Dunn, H. H. The spotted owl (*Syrnium occidentale*). Oologist. 18: 165-167; 1901.
- Dunstan, T. C. Radio-tagging falconiform and strigiform birds. Raptor Res. 6: 93-102; 1972.
- Forsman, E. D. A preliminary investigation of the spotted owl in Oregon. Corvallis, OR: Oregon State University; 1976. 127 p. M.S. Thesis.
- Forsman, E. D.; Meslow, E. C.; Strub, M. J. Spotted owl abundance in young versus old-growth forests, Oregon. Wildl. Soc. Bull. 5: 43-47; 1977.
- Forsman, E. D.; Meslow, E. C.; Wight, A. M. Biology and management of the spotted owl in Oregon. Wildl. Monogr. 87; 1984.
- Gould, G. I., Jr. Distribution of the spotted owl in California. West. Birds. 8: 131-146; 1977.
- Gould, G. I., Jr. Status and management of elf and spotted owls in California. In: Schaeffer, P. P.; Ehlers, S. M., eds. Owls of the west: their ecology and conservation. Proceedings of the symposium; 1979 January 20; San Francisco, CA. Tiburon, CA: National Audubon Society Western Education Center; 1979: 86-97.
- Huey, L. M. Spotted owls in San Diego County. Condor. 15: 229; 1913.
- Ligon, J. S. Habits of the spotted owl (*Syrnium occidentale*). Auk. 43: 421-429; 1926.
- Marcot, B. G.; Gardetto, J. Status of the spotted owl in Six Rivers National Forest, California. West. Birds. 11: 79-87; 1980.
- Marti, C. D. Feeding ecology of four sympatric owls. Condor. 76: 45-61; 1974.
- Mikkola, H. On the activity and food of the pygmy owl (*Glaucidium passerinum*) during breeding. Ornis Fenn. 47: 10-14; 1970.
- Peyton, L. From California. Oologist. 26: 93-94; 1909.
- Postovit, H. A survey of the spotted owl (*Strix occidentalis*) in northwestern Washington. Washington, DC: National Forest Products Association; 1979. 15 p.
- Schemnitz, S. D., ed. Wildlife management techniques manual. Washington, DC: The Wildlife Society; 1980. 686 p.
- Southern, H. N. Tawny owls and their prey. Ibis. 96: 384-410; 1954.
- Taylor, A. L.; Forsman, E. D. Recent range extensions of the barred owl in western North America, including the first records for Oregon. Condor. 78: 560-561; 1976.

**FORSMAN, ERIC D.** Methods and materials for locating and studying spotted owls. Gen. Tech. Rep. PNW-162. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 8 p.

Nocturnal calling surveys are the most effective and most frequently used technique for locating spotted owls. Roosts and general nest locations may be located during the day by calling in suspected roost or nest areas. Specific nest trees are located by: (1) baiting with a live mouse to induce owls to visit the nest, (2) calling in suspected nest areas to stimulate the female to call or fly from the nest, or (3) observing adults during prenesting displays. An effective technique for climbing large nest trees is to rig the tree with a climbing rope. Mechanical climbing aids are then used to ascend the rope. The principal method used to determine the diet is identification and enumeration of prey in regurgitated pellets. The most effective method of trapping spotted owls is with a noose pole. Other trapping methods include mist nets, bal-chatri traps, bow nets, and dip nets. Radio transmitters for long-term radiotelemetry studies are usually attached with a backpack harness; the antenna should be reinforced to keep it from crimping or breaking.

Keywords: Wildlife surveys, birds, owls (spotted).

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